A comparison of the performance of intellectually gifted and average-ability children on four spatial tasks

Elizabeth Edson Block

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A COMPARISON OF THE PERFORMANCE OF INTELLECTUALLY GIFTED AND AVERAGE-ABILITY CHILDREN ON FOUR SPATIAL TASKS

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A comparison of the performance of Intellectually gifted and average-ability children on four spatial tasks

by

Elizabeth Edson Block

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of DOCTOR OF PHILOSOPHY

Major: Child Development

Approved:

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In Charge of Major Work

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For the Major Department

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Iowa State University
Ames, Iowa
1984
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INTRODUCTION

Purpose

The purpose of the present research was to compare the performance of young intellectually gifted children with that of their chronological- and mental-age mates on selected spatial tasks. Differences between the spatial task performances of boys and girls were also examined. Spatial tasks were selected to reflect Piagetian stage characteristics, so that Piagetian stage development could be examined within the research design.

Although the intellectual profiles of gifted children have been discussed in the literature (Callahan, 1979; Hollingworth, 1942; Stanley, Keating, and Fox, 1974; Terman, 1925), the spatial abilities of young children have remained largely uninvestigated (Callahan, 1979). A review of the literature revealed that (a) the range of abilities defined as "spatial" is wide, (b) theoretical approaches vary, resulting in spatial tasks designed to reinforce a variety of viewpoints, (c) few spatial tasks lend themselves to performance by preschool children, and (d) studies of spatial ability in very young children have rarely considered the influence of psychometrically-defined intelligence or mental age. The present research, then, dealt with the relatively unexplored area of spatial ability in very young gifted children.

Review of the Literature

A major difficulty in the area of spatial research is the lack of consensus on the definition of spatial ability. In an extensive review of the literature on human spatial ability, Mark McGee (1979) concluded that
the early identification of a unique spatial factor in intelligence owed itself to studies done in the 1920s, '30s, and '40s aimed at identification of mechanical aptitude. These studies (Brown and Stephenson, 1933; Smith, 1948; Thurstone, 1944) yielded a spatial factor statistically distinct from verbal ability. This spatial measure, according to McGee (1979), was more accurate than intelligence scales or teacher ratings in predicting success in vocational-technical training programs.

More recent studies, again according to McGee's (1979) review, have found a spatial factor among batteries of cognitive test scores from many different racial, ethnic, and socioeconomic groups. McGee noted that recent emphasis on separating out distinct sub-abilities comprising the spatial factor have demonstrated the existence of two spatial factors: visualization and orientation. Visualization generally involves the ability to mentally manipulate, rotate, or invert a stimulus object, a process exemplified by the imagined folding and unfolding of flat patterns. Orientation, on the other hand, involves "the aptitude to remain unconfused by the changing orientation in which a spatial configuration may be presented" (McGee, 1979, p. 893).

In review of the measurement of spatial ability, John Eliot (1980) challenged McGee's (1979) argument for two distinct spatial abilities, claiming that persistently high correlations found between the two indicate the likelihood of a single spatial talent.

Both Eliot (1980) and McGee (1979) addressed themselves briefly to the methodological difficulties inherent in spatial research. In addition to the basic problem of definition, Eliot (1980) pointed out that
variation in population samples and test administration can result in dif-
ferent factor loadings on the same spatial tasks. McGee noted, too, the
disagreement in the field about the classification of spatial tests and
the inadequately researched influence of test-item difficulty. The rela-
tive contribution of two-versus three-dimensional items to spatial ability
is also unknown (McGee, 1979). Possible effects and interactions of age,
sex, and training on spatial performance are inadequately researched

On the whole, the literature on sex differences in spatial abilities
has reported a rather consistent advantage for males, though this advantage
is apparent for the most part only after puberty (Denno, 1981; Fennema,
1974, 1981; Fox, 1977; Harris, 1978; Maccoby and Jacklin, 1974; McGee,
1979). Harris (1978) claimed, in fact, that the difference in spatial
ability is the most consistently found sex difference in cognitive abili-
ties. Fox (1977), however, who has worked extensively with mathematically
gifted adolescents in the Johns Hopkins University Study of Mathematically
Precocious Youth (SMPY), reported that among these gifted children no dif-
fferences in visual-spatial ability were found. Sherman (1977), in a re-
view of studies investigating the possible influence of biological factors
on sex differences in mathematical ability, reported that some samples
failed to show sex-related differences. Her own (1974) research on
spatial visualization found no sex differences in adolescence. Guay
and McDaniel (1977) contributed an interesting insight when they re-
ported that, in a study of mathematical abilities in young children,
even though girls had equivalent scores on tests of lower-level spatial
abilities, males scored higher on tests of the higher-level spatial abilities as early as the second grade. Because the trend in spatial studies has indicated male superiority, however, Sherman (1977) feels that any negative or inconsistent findings regarding that conclusion are "important because they suggest that the sex-related differences in space perception are not incorrigible" (p. 141).

Whereas the spatial research indicates some inconsistencies regarding sex differences, it indicates very little at all regarding the spatial competencies of very young children. In the vast majority of studies reviewed by McGee (1979) and by Eliot (1980), the populations sampled were not young children. McGee (1979) noted that spatially-oriented school subjects (drafting, geometry, mechanics, engineering, physics, etc.) are not generally found in the lower grades. Hence, there may be less incentive for measuring proficiency in these areas in the early childhood years. A more practical difficulty may be the lack of spatial measures suitable for small children, especially pre-schoolers. S. G. Vandenberg (1975) discussed the urgent need for such measures, making this claim: "... a lack of suitable spatial tests presents a major obstacle to further research efforts, regardless of orientation" (p. 57).

Even less common than studies involving spatial ability in very young children are studies examining whether intellectually gifted children excel at spatial tasks. In fact, a computer search of Psychological Abstracts from 1967 to 1983 revealed only four studies of spatial ability in gifted children of any age. There have been studies that looked at the effect of IQ or mental age on spatial performance without specifically including the
upper end of the intelligence spectrum, and pertinent results of such investigations will be outlined in the present literature review.

Although the lament of McGee (1979) and Eliot (1980) concerned the neglect of very young children in the spatial literature, there has been one theoretical, as well as methodological, approach that has focused directly on the spatial development of children from the cradle onward—the extensive contribution of Jean Piaget. In The Child's Conception of Space (1956), Piaget and Inhelder outlined the child's progression through a series of cognitive stages, stages that represent qualitatively distinct ways of looking at, and making judgments about, space. Roughly speaking, the first stage, lasting until about the age of seven or eight, is that of "topological space," defined by "relations of proximity, separation, order, enclosure and continuity...built up empirically between the various parts of figures or patterns which they organize" (p. 153). This stage is followed by those of projective and Euclidean space, both of which are related to one another and which involve "locating objects and their configurations relative to one another, in accordance with--projective systems" (p. 153). Piaget and Inhelder (1956) went on to describe several experiments designed to determine whether the child had acquired such a projective skill, and several of these experiments were adapted for use in the present study.

Because of their adaptability for use with children, and because of their compatibility with Piagetian stage theory in general, some of the spatial measures of Piaget and Inhelder have been widely replicated. The "three mountains" task, in particular, has been fairly extensively
researched, though not always with corroborative results (Fishbein, Lewis, and Keiffer, 1971; Lovell, 1959; Shantz, 1971). Other spatial tasks of Piaget and Inhelder that have reappeared in various adaptations and replications have been the water level task, the projection of a straight line, and various paper-folding tasks (McGee, 1979).

There have been attempts to quantify the scoring of these Piagetian spatial tasks and to correlate the resulting performance levels with other measures (even other Piagetian spatial measures), as well as measures of overall intellectual ability. There are, additionally, attempts to quantify Piagetian tasks of a nonspatial nature, and to correlate these measures with psychometric intelligence scores, but the present study focuses upon spatial tasks and will confine itself largely to the literature reflecting spatial competence as it is affected by sex, chronological and mental age, and type of spatial task utilized.

To review chronologically: Lovell (1959) undertook a follow-up on some of the spatial tasks proposed by Piaget and Inhelder (1956). Lovell's interest was in whether nursery school children did indeed perform as Piaget and Inhelder had predicted on tasks of haptic perception, spatial relations in drawing, linear and circular order, perspective drawing, knot-tying, and the projection of a straight line. Subjects were 140 children ranging from two to six years. Regarding spatial tasks in general, Lovell found his subjects demonstrated competence in advance of the age Piaget and Inhelder had described, and further, that the question of the inevitability of topological concepts of space preceding projective and Euclidean concepts should not be closed.
Dodwell (1963) also attempted to re-examine the questions about spatial development raised by Piaget and Inhelder (1956). The subjects were 194 children, ages 5-11 years. IQs (name of IQ measure not given) ranged from 80 to 136, with no IQs available for kindergarten subjects. The author stated that the average IQ range was over-represented at the expense of the extremes. Tasks included items on perspective, similarity and proportion, geometrical sections, horizontal and vertical coordinates, geometric figures, shape drawing, and the construction of a straight line. Dodwell found that performance on his seven tasks taken as a whole correlated "considerably" with chronological age (+.56), and even more strongly with mental age (+.69), while the correlation with IQ was less definite (+.31). Significance levels of correlations were not given.

Dudek, Lester, Goldberg, and Dyer (1969) reported an extensive longitudinal study involving 100 school children as they progressed from kindergarten to grade two (from five to eight years). All children were individually administered the WISC, Lincoln-Oseretzsky, and nine Piagetian tasks. The Lorge-Thorndike was given in small group (four to five children) settings. The entire test battery was repeated at each of the three grade levels. Scholastic achievement was measured with the California Achievement Test (CAT) at the end of grades one and two. The CAT yields separate arithmetic, language, and spelling, as well as total, scores. The nine Piagetian tasks included a spatial perspective-taking task, a task involving linear order, and seven other nonspatial tasks assessing artificialism, notions of time, origin of dreams, conservation, inclusion, and seriation. Intercorrelations of the nine Piagetian tasks were high and reliable. A
significantly high relationship was found between the Piagetian task overall score and the Lorge-Thorndike and WISC scores at all three grade levels. As to achievement, Piagetian tasks were slightly better predictors of achievement than the WISC in kindergarten. In grades one and two, both measures predicted achievement equally well.

Laurendeau and Pinard (1970), in a landmark study involving approximately 700 children aged 2 to 12 years, sought to examine children's performance on five Piagetian tasks, including stereognostic perception, construction of a projective straight line, localization of topographical positions, left-right concepts, and the coordination of perspectives. Psychometric intelligence wasn't a variable of interest in this study; therefore, Laurendeau and Pinard's discussion sheds little light on the issue of psychometric versus Piagetian measures. Their results are, of course, extremely useful in comparing chronological ages at which certain Piagetian spatial tasks are mastered.

Stephens, McLaughlin, Miller and Glass (1972) studied relationships among 27 Piagetian assessments and standard measures of intelligence and achievement. A sample of 150 children was comprised of 75 average-ability (IQ 90-110) and 75 retarded (IQ 50-75) children from three age ranges, equally represented within each group: 6-10 years, 10-14 years, and 14-18 years. Piagetian reasoning assessments included conservation tasks, classification experiments, spatial items, and one formal operations task. The spatial tasks included rotation tasks, transfer from two to three dimensions, and coordination of perspectives. Standard Wechsler scales were used as intelligence measures, and the Wide Range Achievement (WRA)
test provided reading, spelling, and arithmetic scores. Five separate factors were obtained from factor analysis of scores for Piagetian reasoning, intelligence, and achievement. Their factor labeled "#4," defined by Piagetian spatial operations measures, had loadings from both chronological and mental age. "Factor #1," by contrast, was defined by Wechsler and Wide Range Achievement Scores. The conclusion of Stephens et al. (1972) from their data was that "... Piagetian reasoning tasks involve abilities separate from those measured by standard tests of intelligence and achievement" (p. 343).

A longitudinal study (Goldberg and Meredith, 1974) examined the performance of 76 high school students, all of whom had taken at least one or more of five Piagetian spatial measures as elementary students, on four different spatial ability tests (a "cards" test from the Primary Mental Abilities Test, a form board test, a paper-folding test, and a mental rotations task). The earlier tests had been "perspectives," "water level," "tracks," "geometric forms," and "houseplans." The original five tests and the later four were correlated and factor-analyzed. Unfortunately, intelligence scores (California Test for Mental Maturity) were only available for 16 of the subjects. These IQ scores failed to correlate with spatial task performance. Goldberg and Meredith (1974) found that the Piagetian "Water" and "Houseplans" tasks correlated significantly, p<.05, with the later spatial tasks. This same study reported significant, p<.05, sex differences favoring males in only two tasks, "Houseplans" (a Piagetian task administered to the subjects in elementary school), and the "Mental Rotations" task (a spatial task administered to the subjects in
DeVries (1974) reported on relations among Piagetian, IQ, and achievement measures. Subjects were 143 bright, average, and retarded children aged five to seven years. The 15 Piagetian tasks included a left-right perspective item that is considered spatial in nature, and this task was found to relate to mental age on the Stanford-Binet. A factor analysis of Stanford-Binet mental age, the 15 Piagetian tasks, the California Test of Mental Maturity (CTMM), and the Metropolitan Achievement Test (MAT) resulted in the emergence of four main factors: (a) Stanford-Binet mental age, CTMM IQ, left-right perspective and two other Piagetian items, (b) principally conservation tasks, (c) MAT subtests, and (4) identity and sorting tasks.

Lehman and Erdwins (1982) compared the performance of 16 bright (mean IQ = 152) third graders with 16 average-ability third graders and 16 average-ability sixth graders (IQs 90-110) on perceptual, affective, and cognitive perspective-taking tasks. Role-taking skills of the psychologically gifted children were more similar to those of their mental age-mates (the sixth graders) than to those of their chronological age-mates (the average third-graders) on both the affective and cognitive tasks. On the perceptual task (a perspective-taking task designed originally by Fishbein, Lewis, and Keiffer, 1971), the gifted children's performance fell between that of their chronological- and mental-age mates.

From the foregoing review, it can be noted that a wide variety of tasks have been encompassed by the term "spatial ability," including left-right perspective items, form board tests, water-level problems, problems
dealing with perceptions of horizontal and vertical, block tests, rotation and paper-folding items, geometric sections, transfer from two to three dimensions, field independence items, linear order and reversed linear order, the projection of a straight line, knot tying, haptic perception, shape recognition and shape drawing, and rod-and-frame tests, just to name those touched upon in the studies already reviewed.

Whether or not these all represent facets of the same spatial ability is still a point of discussion in the literature, although both McGee (1979) and Eliot (1980) state in their reviews that significant relationships have been found to exist among the various spatial tasks. The present study will include four tasks involving the mental rotation of geometric shapes. Although they will be referred to as tests of spatial ability, it is not intended to imply that all facets of spatial ability are measured by these tasks.

Also evident from the foregoing review is the inconsistency in the literature as to the effect of certain variables upon spatial performance. Of the studies of a variety of Piagetian spatial competencies reviewed here, all imply some developmental aspect associated with chronological age, though not all report ages of mastery of given tasks that agree with the predictions of Piaget and Inhelder in 1956 (Laurendeau and Pinard, 1970; Lovell, 1959). Mental age was found to be a significant factor in the success at spatial tasks reported by Dodwell (1963), Stephens et al. (1972), and DeVries (1974). The question of the impact of IQ on spatial performance is less clear. Dodwell (1963) reported a correlation of .31 between IQ and spatial task performance; lower than that for mental age
and task performance (.22). Dudek et al. (1969) found a significant correlation between spatial ability and IQ, but Stephens et al. (1972) found chronological and mental age were both more highly correlated with spatial ability than was IQ. Goldberg and Meredith (1974) found no significant relation between IQ and spatial performance, while DeVries (1974) found, by factor analysis, that mental age, IQ, and spatial ability all loaded on the same factor. For Lehman and Erdwins, the spatial performance of gifted third-graders fell between that of their chronological and mental age comparison.

The inconsistency in the findings reviewed above is compounded by the methodological inconsistencies in the studies. Age level of subjects, type of spatial measures and intelligence scales employed, difficulty of spatial items, and research questions of interest all varied from study to study. Only two studies (Laurendeau and Pinard, 1970; Lovell, 1959) looked at performance of preschoolers, and these two did not consider the IQ as a variable of interest. Giftedness was a factor considered only in the work of DeVries (1974) and Lehman and Erdwins (1982), neither of whom used preschoolers.

Selection of Research Tasks

The range of tasks reported in the literature and considered to be "spatial" is wide indeed. The selection of spatial items for the present study was dictated by the following considerations: First, tasks were desired which would either be drawn directly from Piagetian sources or which seemed likely to reflect Piagetian competencies, such as the mental rotation of surfaces, described by Piaget and Inhelder (1956). Also,
tasks were selected to range from items simple enough to be accomplished by at least some of the average-ability 4-year-olds to items difficult enough to challenge average-ability 10- or 11-year-olds.

In addition, tasks were selected to eliminate from the task design the methodological complication of requiring the children to draw their responses. It has been debated in the literature whether or not such a requirement introduces the confounding variable of motor skill (Dean, 1982; Dean and Scherzer, 1982; Marmor, 1975). A method of response other than drawing was therefore desirable.

Further, all tasks were presented in a visually-displayed, multiple choice format, according to which children would be given three options from which to select an answer on each task item: One option (scored as a "1") would be the correct response, another option (scored as a "2") would be an intermediate response, and a third option (scored as a "3") would be the least correct response. For each task item, a spatial model would be presented and the child asked to perform some mental manipulation on it. The child would then be asked to match the resulting mental image with one of the three given response choices. These response choices would be designed, then, to reflect one choice which would be correct and which would represent the most advanced Piagetian stage. A second choice would reflect some grasp of the model's topological features though it might indicate less-than-perfect mental rotation or less-than-complete consideration of topological aspects, such as proximity, continuity, or enclosure. A third choice would show the least consideration of topological features. The three-step stage progression could later be analyzed statistically to
see whether the response choices did indeed reveal a stage-like progression and not simply an increasing ability to select the one correct response choice.

Four types of tasks were selected which fulfilled the foregoing criteria, as well as the more practical demands of size, cost, and sophistication of construction. All tasks involved the mental rotation of geometric shapes.

The first two task categories, involving the mental rotation on a plane of two- and three-dimensional shapes, were not specifically described by Piaget, though they seem to reflect Piagetian developmental concepts. In particular, these first two types of tasks resemble the rotating squares task (Piaget and Inhelder, 1971), which requires children to imagine how a square will appear after it has been rotated a given number of degrees. Briefly, Piaget and Inhelder (1971) concluded that 5- and 6-year-olds were incapable of mental rotation, 7- to 9-year-olds were in an intermediate stage, grasping some aspects of rotation but not others, and only the 10- and 11-year-olds in the sample were capable of imagining the image of the rotated square correctly and reliably. It should be noted, however, that the children in Piaget and Inhelder's (1971) research were required to draw their mental images of the rotated square. If drawing introduces another variable, and it seems that at the very least it is a different sort of response than choosing a response from a given selection, then the results of Piaget and Inhelder on this task are not directly comparable with the results in the present research.
It is appropriate to mention at this point the work of a school of researchers who have combined the notions of Piagetian stage development with the information-processing theorists, who prefer to study children's rotation using a reaction-time procedure. Spokesperson for this school is Anne Dean, who has conducted research on the rotating squares task, measuring both reaction time and level of Piagetian stage development of children's responses (Dean, 1982; Dean and Scherzer, 1982). Dean's conclusion was that reaction-time and drawing measures of children's mental rotation suggested a similar quality of imaging. Her subjects, however, were 48 middle and lower-middle class girls in New Orleans, La. Ages ranged from 5.6 to 13.8 years, with a mean age of 9.2. The possibility of sex-related performances cannot be overlooked.

Another line of investigation stemming from the work of Piaget has been that dealing with the problem of perspective-taking, which involves the ability to take a visual point of view other than one's own. It is difficult to say whether this task of assuming another's point of view is indeed the same as mentally manipulating the object being viewed, but certainly both involve a mental operation, spatial in nature, that results in imagining what something looks like from another angle. The mental rotation of two- and three-dimensional objects displays aspects of other Piagetian developmental notions as well, such as left-right perspective and the rotation of surfaces.

Fishbein, Lewis, and Keiffer (1971) pointed out that success at the more traditional Piagetian perspective-taking tasks (in particular the egocentrism task typified by the "three mountains" study) is affected by
such task variables as instruction, familiarity, stimulus number and complexity, and mode of response required. As to the related tasks of the mental rotation of two- and three-dimensional geometric forms, Stephens et al. (1972) found that such tasks loaded on a factor also characterized by chronological and mental age. Goldberg and Meredith (1974) found no significant correlation between IQ and performance on two- and three-dimensional rotation items.

In the chapter "The Rotation and Development of Surfaces," Piaget and Inhelder (1956) described a paper-folding task in which children were asked to imagine and draw what certain geometric solids would look like if their outer surfaces were unfolded and laid flat. In Goldberg and Meredith's (1974) article, two paper-folding tasks were incorporated. For the 16 subjects who took an intelligence test as well as a paper-folding task, there was no significant correlation between the two scores. Shepherd and Feng (1972), who belong to the information-processing school, conducted a paper-folding study which, while it did not take a Piagetian approach and did not consider the variable of intelligence, did reveal that the difficulty of such tasks, as solved by adults, and as measured by the time required for problem solution, was a linear function of "sum of number of squares (mentally) carried along for each fold" (p. 232). This consideration was useful in the design of the present study, suggesting that the sample paper-folding tasks should be characterized by a minimal number of folds.

In their chapter "Geometric Section," Piaget and Inhelder (1956) described an experiment in which a child was shown a geometric solid (for
example, a cylinder), was told to imagine that the solid was cut through at a given location and angle, and was requested to determine what the resulting exposed surface would look like. Dodwell (1963) used this task as one of the seven spatial items used in his study. In his presentation, children were asked to draw what they thought the side where it had been cut would look like. Dodwell found that children's responses do reflect the stages described by Piaget. In the present study, the response choices for the cross-section task items were patterned, insofar as was possible, after the actual drawings made by children in response to the cross-section problems presented in Piaget and Inhelder's research (1956, pp. 247-271).

Research Hypotheses

The null hypotheses to be tested by the data analysis are as follows:

1. There are no relationships among the performances on four different spatial task-types involving the mental manipulation or rotation of geometric surfaces.

2. There is no relationship between the ability to perform these spatial tasks and chronological age of the subject.

3. There is no relationship between the ability to perform these spatial tasks and mental age of the subject.

4. There is no effect of sex upon the ability to perform these spatial tasks.

5. There is no effect of group (gifted, chronological-age match, and mental-age match) upon the ability to perform these spatial tasks.
6. There is no relationship between group and choice of incorrect response (an indication of stage-like development) to spatial tasks.
METHOD

Subjects

The subjects for this research were 63 children drawn from the community of Ames, Iowa, and from the nearby consolidated elementary school at Gilbert, Iowa. The Ames children were all either currently enrolled in, or had previously attended, the Iowa State University Child Development Laboratory Schools. Of the 63 children, 57 were white, 5 were Oriental, and 1 was black. There were 31 males and 32 females.

In accordance with the research design, children were assigned to one of three groups. The high-ability, or gifted, group consisted of 21 children (seven 4-year-olds, seven 5-year-olds, and seven 6-year-olds), all of whom had scored 130 or higher on an individually-administered Stanford-Binet Intelligence Scale, Form L-M, 1972 norms. One exception was made to this requirement by including a child with an IQ of 122. This exception is explained in the "Procedure" section of this paper. (See Table 1 for an outline of group characteristics.) In Table 1, the gifted IQ range of 122-164 includes one IQ of 164 which was extrapolated, since Stanford-Binet norms don't extend that far. A second group consisted of 21 children matched for chronological age to the gifted group, but having Stanford-Binet scores ranging from 86 to 115. A third group was composed of 21 children matched to the Stanford-Binet "mental ages" achieved by the gifted group, but having IQ scores ranging from 89 to 113. The chronological ages of this third group ranged from 6 years, 11 months to 11 years, 3 months. Average IQs of the three groups were as follows: gifted, 143.3; chronological-age (CA) matched, 104.7; and mental-age (MA) matched, 104.4.
Table 1. Groups by chronological age (CA), mental age (MA), IQ: Means and ranges n = 21 per group

<table>
<thead>
<tr>
<th>Groups</th>
<th>Gifted</th>
<th>CA match</th>
<th>MA match</th>
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<tr>
<td>mean</td>
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<td>67.2</td>
<td>92.7</td>
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<td>Mental age:</td>
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<td>range</td>
<td>82-140</td>
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<td>IQ:</td>
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<tr>
<td>mean</td>
<td>143.3</td>
<td>104.7</td>
<td>104.4</td>
</tr>
<tr>
<td>range</td>
<td>122-164</td>
<td>86-116</td>
<td>89-113</td>
</tr>
</tbody>
</table>

Note: All ages reported in months.

Apparatus

IQ measure

The abbreviated form of the Stanford-Binet Intelligence Scale (Form L-M, 1972 norms) was the intelligence measure used in determining IQs and mental ages for all subjects in the study.

Spatial tasks

Because the spatial apparatus used in the present study were fairly complex, and because their physical appearance is so crucial to any understanding of the process and results, it is suggested that the reader
accompany the verbal description that follows with frequent references to Appendices A-D, which contain sketches and measurements of the spatial instruments.

Briefly, there were 24 spatial items used in this research, 6 each of four basic types of tasks. Of these 6 items, 2 were used, in each case, as teaching models to familiarize subjects with the tasks, and the remaining 4 were scored items. Thus, each subject was presented with a total of 16 scored spatial items, 4 each of four types of tasks. These four groups of tasks will be referred to as the Puzzles, the Lego, the Paper-folding, and the Cross-sections tasks. Individual scored tasks are also referred to by task number, and can be identified in Appendices A-D.

Each of the 24 tasks followed a similar format, in that a spatial model form was presented to the child, the child was asked to mentally picture the model form in some altered aspect, and then the child was required to select which of three presented response forms correctly represented the child's mental picture. In this respect, the study resembled a multiple-choice exercise, with 16 scored responses, selected in each case from a three-choice answer list. In Appendices A-D, then, are pictured 24 spatial tasks, each consisting of one spatial "model" form and three possible "response" forms.

In the first set of tasks, the Puzzle tasks, the subject was first shown a flat yellow cardboard model form resembling a geometrically-shaped puzzle piece (Appendix A). The response board for each of the six puzzle items consisted of a white puzzle frame, two cardboards thick, into which were cut three puzzle forms, all yellow, all resembling in some ways
the model piece, but only one of which would perfectly match the model form if it were rotated 180°. The model forms were presented against a white cardboard background similar to the background of the puzzle frame composing the response board, and in the two training samples, the model forms could actually be rotated on the cardboard for demonstration purposes, while for the four scored items, the model "puzzle" forms were glued to the cardboard and could not be rotated, thus requiring the subject to perform the operation mentally.

In the second set of tasks, the Lego tasks (see Appendix B), subjects were first shown a very simple model form of from two to four toy Lego bricks, glued together and displayed on a white cardboard. Again, in the two sample items, the model form could be physically rotated on the white background, while for the four scored items, the model forms were glued down, requiring the operation to be performed in the child's imagination. The response boards for the six Lego items consisted of six white cardboards with three small Lego constructions glued to each. All three response choices resembled the model form in some way, but only one response constituted a perfect replica of the model form rotated 180° against its base.

For the third set of tasks, the Paper-folding tasks, (see Appendix C) children were first shown a model geometric three-dimensional form constructed from folded white cardboard. In the two sample items, the model could be physically unfolded to display its flattened, unfolded shape. In the four scored items, the model form was glued together, so that the model (whether cube, cylinder, or whatever) could be viewed only in its
three-dimensional form, albeit from any angle. The response boards for these items, then, consisted of yellow cardboard rectangles displaying three actual unfolded white cardboard forms, all of which resembled in some ways the unfolded shape of the model form, but only one of which matched it precisely.

In the final task set, the Cross-sections (Appendix D), the children were shown a model wooden geometric form with a black line on it representing the perimeter of the plane through which the children were to imagine a cross-section being cut. In the case of the two sample items, children were also shown the two parts of a geometric shape identical to the model shape which had actually been cut through the plane indicated by the black line. These two dissected model forms were blackened across the exposed cut plane, or cross-section, in order to emphasize for the children exactly what constituted the cross-section. Each response form for the Cross-section items consisted of a white cardboard with three black geometric shapes drawn on in heavy black marker. All three shapes resembled in some way the indicated cross-section of the model form, but only one was an exact representation.

All puzzle shapes, folded structures, and response boards were covered with clear Con-tac paper in order to increase their durability and enhance their appearance.

During the administration of the spatial tasks, the experimenter made use of a one-page sheet containing both verbatim instructions to be given each child and small sketches of the 24 response boards upon which to mark subjects' answers to demonstration and scored items (see Appendix E).
Procedure

Permission to conduct this research was first sought from the Iowa State University Committee on the Use of Human Subjects in Research. The committee concluded that 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.

Written parental permission was obtained prior to involving any child in either pilot testing or in the research study itself.

Pilot testing was conducted on children from the Iowa State University Child Development Laboratory Schools to determine the appropriateness of the spatial tasks. Children involved in the pilot testing were not used for the research study.

In order to establish a sample of subjects that would consist of gifted (IQ = 130+) children and their chronological- and mental-age matches, it first was necessary to identify the 21 gifted children. It was desirable to find seven 4-year-olds, seven 5-year-olds, and seven 6-year-olds. The instrument used was the abbreviated form of the Stanford-Binet Intelligence Scale. Of the 21 high-ability children selected, 16 were drawn from the past and present ranks of Project Pegasus, a pre-school for gifted youngsters that is part of the Iowa State University Child Development program. The rest of the gifted children, as well as the children in the chronological- and mental-age matching groups were drawn from the other Child Development Laboratory Schools (a
preschool, a day care, a kindergarten, and an older children's laboratory), from the Ames community, and from the consolidated Gilbert Elementary School in Gilbert, Iowa.

Once the group of twenty-one 4-, 5-, and 6-year-olds of high ability was identified, their average-ability chronological- and mental-age mates were sought. The chronological and mental ages of the gifted children were recorded in numbers of months, and average-ability matches were sought, for each child, within 3 months of chronological and mental age.

In the case of the mental-age matches, three exceptions were made to the stipulation of matching mental age within 3 months; a 4-month, a 5-month, and a 7-month match. Table 1 (p. 20) summarizes characteristics of the resulting sample of 63 subjects.

It was originally hoped that chronological- and mental-age matches could be found who would, while closely fulfilling the age-matching stipulation of 3 months, still fall strictly within a narrowly-defined "average" IQ range of 90-110. Of the 42 average-ability subjects, 28 met this requirement. However, because of practical limitations of time, money for test administration, and availability of subjects, 10 additional subjects whose IQs fell in the 87-113 range were accepted, plus 4 more with IQs of 86, 114, 115, and 115, respectively.

There was also one exception to the requirement that children in the gifted group have an IQ of 130 or more. One boy whose IQ was measured at 122 was accepted because of the following reasons: (a) He had a previously-recorded IQ score of 142. (b) He was personally known to the current researcher and two colleagues and was judged to be of superior
mental ability. (c) He became restless during the administration of his "qualifying" Stanford-Binet and was anxious to leave the testing situation, even missing some items on the test which he had previously answered correctly.

The resultant sample consisted of 21 gifted, 21 chronological-age (CA) matched, and 21 mental-age (MA) matched subjects with group IQs averaging 143.3, 104.7, and 104.4, respectively.

The Stanford-Binet Intelligence Scale, Form L-M, was selected as the measure for the subjects' intelligence for the following reasons: (a) It is an extensively standardized measure that can be used on young children. (b) It is an individually administered test. (c) It is a test with which the present researcher has considerable experience in administration and interpretation.

The Stanford-Binet Intelligence Scale was administered on an individual basis to each subject (as well as to the many other children whose IQs placed them outside ranges acceptable for this study) by a female graduate student in Child Development. Testing was done either in research rooms or in small, quiet private offices. In the majority of cases, children were taken from classrooms to testing rooms within the same building. However, children from the Ames community were brought by their parents to be tested in the Child Development research rooms after school and on Saturdays. Administration of the Stanford-Binet in its
abbreviated form requires about 30 minutes. All Stanford-Binet Scales and all spatial tests were administered within a nine-week period in the Spring of 1983.

The spatial testing was done by another female graduate student in Child Development, in a testing session separate from the intelligence test administration. Because the present author was familiar with some of the subjects in the study, none of the spatial tests were conducted by her. For the purpose of clarity, the graduate student doing the spatial testing will be referred to as the "examiner." Appendix E contains the instructions (and the answer sheet) used upon the occasion of the spatial testing, and will serve as a useful outline in the description of the testing procedure.

The spatial tasks were arranged in a research room (or a teacher's work room, in the case of the Gilbert school children), displayed on tables in such a manner that the child could see all the items spread out in the room and could simply proceed, along with the examiner, from one item to the next. The entire spatial testing session usually required only about 10-15 minutes per child.

As has been mentioned in the "Apparatus" section, each task group consisted of six items; two samples, and four scored items. After establishing rapport with friendly conversation, the examiner introduced the spatial tasks by saying, "I'm going to show you some puzzles, but these puzzles are just for looking at. You won't need to touch them at all. I'll hold them so you can see them." These directions served to introduce the tasks and encourage the child to perform only mental, not physical,
actions upon the spatial devices.

The first task group was the puzzle tasks, in which the child was asked into which of three indented yellow spaces in a white board a yellow geometric cardboard puzzle form would fit. For the two demonstration items, the examiner said, "Look, here is a puzzle piece." The examiner held the model form before the child, lifting it off its white background form to do so. "And here are three places it might fit." The three response choices were pointed out. "But it will really only fit in one place. You can see I'll have to turn the piece to make it fit somewhere." Now the examiner rotated the model form $180^\circ$ and back to its original position twice. "I'll turn the piece. Now, does it fit here, or here, or here?" With these instructions, the rotated model form was held next to each response choice in turn, so that the subject could more clearly see which of the three indented spaces would contain the rotated form. When children were shown in this way how to select the correct response, they were, without exception, able to do so. The instructions were repeated for the second demonstration item.

For the scored puzzle items the instructions were modified somewhat. "Now look. Here is another piece, and three places it might fit." The model puzzle piece glued to its white cardboard background was pointed out, as were the three possible indented spaces where it might fit. "But see? This piece is glued down. You will have to pretend to turn it in your mind." The examiner then made a turning motion with her hand over the puzzle piece that the child was to mentally manipulate. "You'll have to imagine how it will look after you turn it, so that you can see where
it will fit. So if you turn the piece, where will it fit? Will it fit here, or here, or here?" The three response spaces were pointed out in turn. The child made a selection, which the examiner marked down on the answer sheet.

For the remaining three puzzle items, instructions were repeated in a somewhat shortened form (see Appendix E for precise wording). It often happened, however, that children "caught on" to the consistent pattern of the instructions and made their selections before instructions were complete. Such responses generally were accepted, as long as the instructions had been heard in their entirety at least once.

For the Lego task, instructions were given in a manner very similar to that of the puzzle task. For the two demonstration items, the examiner said, "Now look. Here are some little Lego blocks. These three are glued down, and this one I can turn." Here, the examiner indicated the response choices, all glued to a white cardboard background, and then the model Lego construction form which was rotated 180° and back twice to demonstrate its appearance in the rotated position. "If I turn this one, it will look just like one of these, but only one of them. I'll turn it and you decide. Does it match this one, or this one, or this one?" The rotated model was then held next to each of the three response choices in turn. As before, subjects were able to follow these instructions without difficulty.

For the scored Lego items, instructions were modified as follows: "Now see these Lego pieces." The model construction form for the first scored Lego item was displayed, glued to its white cardboard background. "This one [the model one] is glued down too, just like these three [the
response choices]. You will need to pretend to turn it in your mind. You will have to imagine how it will look after you turn it so that you can decide which one it matches. So, if you turn the piece, will it match this one, or this one, or this one?" Each of the three response choices was pointed out in turn. The child's response was recorded and the examiner continued.

For the remaining three scored Lego items, instructions were shortened somewhat (see Appendix E) and again, children often responded before instructions were quite out of the examiner's mouth.

The next set of tasks was the Paper-folding items. Instructions began, "Now look here. This is a different kind of thing. It's a cardboard shape that I can unfold. When it's folded it looks like this, but when it's unfolded, it will lie flat like this." Both positions of the foldable shape were demonstrated. "Now, when I unfold it, it will match one of these three unfolded shapes, but only one. Will it match this one, or this one, or this one?" The examiner unfolded the three-dimensional shape and held the flattened model form next to the three unfolded response forms in turn.

After the child was presented with the two demonstration items, the scored items were offered. Instructions began, "Now look at this cardboard shape. It's all glued together so I can't unfold it. You will have to pretend to unfold it in your mind." Here, the examiner displayed all sides of the folded, glued model form, and then made imaginary "unfolding" motions near the folded model. "You'll have to imagine how it will look after you unfold it so you can see which one of these it will
match. So if you unfolded it, would it match this one, or this one, or this one?" Each response choice was indicated. After marking the child's selection on the answer sheet, the examiner continued with the somewhat abbreviated form of these instructions for the remaining three Paper-folding items (see Appendix E for precise wording).

For the final tasks, the Cross-sections, instructions began, "Here is one last set of things. Look, here is a block of wood. See, it has a black line around it." The examiner showed the subject a small wooden sphere with a black line drawn around its circumference. "Now, I'm going to take a knife and pretend to cut the block apart on this line." A sawing motion was made with a kitchen knife above the black line drawn around its circumference. "Now, I'm going to take a knife and pretend to cut the block apart on this line." A sawing motion was made with a kitchen knife above the black line, as though to cut through the sphere on the indicated plane. "See, I have another block just like this one that really is cut apart. If I really cut it apart, it would break open like this, wouldn't it?" Here the examiner showed the child a bisected wooden sphere. The faces of the two resulting cross-sections were first held together, and then "broken" open to demonstrate the desired concept. One circular cross-section was blackened in, to emphasize the point that the "cut part," or the cross-section, would be shaped like a circle. "See, this part I've painted black is where it would be cut by the knife. Now this cut part would match one of these three black shapes, but only one. Would it match this one or this one or this one?" The blackened cross-section was held next to the three response shapes, all drawn in solid
black on white cardboard.

It may be noted that, in spite of what seemed a fairly complex task here, not one of the children seemed at a loss to make a selection. There were no looks of bewilderment, no lengthy response lags, and no "I-don't-get-it's" by the children.

After repeating the directions for the second demonstration item and noting the child's response, the researcher proceeded to the scored items. "Now, look at this block of wood. It has a black line to cut on too. But I don't have one like this one that's really cut apart. You'll have to pretend to cut it apart in your mind. You'll have to imagine how the cut part would look if you really cut it apart with the knife." At this point the researcher made the sawing motion with the knife on a plane with the black line. Then, with the first scored item only, she made a breaking-apart motion with her hands. "If I really cut it apart, would the cut part look like this or this or this?" A gesture was made to each of the response choices in turn. Reference to Appendix E will show that the instructions to the final three items are an abbreviated form of the instructions for the first scored cross-sections item. Also, in the last three Cross-sections tasks, the examiner accompanied her verbal instructions with the indicative sawing motion of the knife, but without the "breaking-open" motion of her hands, thus leaving a little more to the children's imaginations in these last three items. Subjects' choices were marked on the answer sheet.

After completing all the items, the child was returned to the classroom, or, in the case of the children brought by their parents from the
surrounding community, the child was returned to the parent.

Scoring

The spatial instrument consisted of 16 forced-choice items, with no examiner subjectivity involved. On each of the 16 scored items, children were assigned a score of 1, 2, or 3, based upon their response choices. A lower score was "more nearly correct." A score of 1 indicated the single correct choice, but a score of 2 was considered "more nearly correct" in some Piagetian or geometric sense than a score of 3. The rationale behind this scoring system was treated more extensively in the Introduction section of this paper.

On each set of 4 scored task items, then, children could score a total of from 4 to 12 points, with 4 representing a perfect score. By totalling the score on all 16 items, a child could achieve from 16 to 48 points, with 16 representing a perfect score on all items. Actual mean scores achieved by subjects within groups can be noted in Table 4 (p. 39).

Statistical Treatment of the Data

Independent variables in the present study are chronological age, mental age, sex, and group (gifted, CA match, and MA match). Dependent variables are scores on spatial tasks. In the statistical analyses, data will be subjected to analyses of variance (ANOVA), t-tests, Pearson correlations, first-order (partial) correlations, and Chi-square tests. Significance of statistical tests will be sought at the .05 and .01 levels.
RESULTS

In the following discussion on the results of the present study, the 16 separate tasks will be referred to sometimes as individual tasks, sometimes as subgroups of 4 tasks each, and sometimes collectively as a single spatial instrument. To clarify the reporting of results, then, it will be helpful to assign descriptive labels to these individual tasks and task groupings. Individual tasks will be referred to by their task category plus a number, such as Puzzle 1 or Cross-section 3 (See Appendices A-D). The task sub-groups will be referred to by their category preceded by the word "Total," as in "Total Paper-folding." The 16 items considered as a single instrument will be termed "Total Spatial."

Because the spatial tasks were devised by the present author and were not part of any standardized instrument, it was desirable to examine inter-task correlations among individual tasks, task sub-groups, and Total Spatial score. A table displaying Pearson correlation coefficients among the 16 individual tasks and their sub-group totals and the Total Spatial score is found in Appendix F (Table F1). Although part-whole correlations are reported in Table 2 and Appendix F, it is recognized that, because of the part-whole relationship, they are spuriously high.

In terms of inter-task correlations within task subgroups and with subgroup totals and Total Spatial, the Puzzle tasks appear to be the least successful. Of the six possible paired combinations of individual Puzzle tasks, none were significantly correlated, and only two of the individual tasks (Puzzle 1 and Puzzle 4) correlated significantly, $p<.01$, with the Total Spatial score. All four Puzzle tasks did, however, correlate significantly, $p<.01$, with the Total Puzzles score.
The Lego tasks fared a little better, with Lego 1 and Lego 3 significantly correlated, $r(61) = .32, p < .01$, as well as Lego 2 and Lego 3, $r(61) = .25, p < .05$. All Lego tasks correlated significantly, $p < .01$, with Total Lego. Lego 1, 2, and 3 correlated significantly, $p < .05$, with Total Spatial.

Among the Paper-folding subgroup there were no significant positive correlations among tasks. The Paper-folding subgroup also contained the single instance where two tasks within the same group (Paper-folding 3 and Paper-folding 4) actually displayed a significant negative correlation, $r(61) = -.27, p < .05$. Paper-folding 4 was also the only Paper-folding task which failed to correlate significantly and positively with Total Spatial. All Paper-folding tasks did, however, correlate significantly and positively with Total Paper-folding, $p < .01$.

The Cross-sections subgroup proved the most fruitful in terms of significant correlations among tasks: Cross-sections 1 and 2, $r(61) = .24, p < .05$; Cross-sections 1 and 3, $r(61) = .22, p < .05$; Cross-sections 2 and 3, $r(61) = .39, p < .001$; and Cross-sections 3 and 4, $r(61) = .44, p < .000$. Additionally, all four Cross-sections tasks correlated significantly with Total Cross-sections and with Total Spatial, $p < .001$.

Table 2 (p. 35) indicates how well the subgroups themselves correlated with one another and with the Total Spatial score. The Total Puzzles correlated with the Total Lego, $r(61) = .27, p < .05$, and with the Total Cross-sections, $r(61) = .29, p < .01$. Additionally, Total Lego correlated with Total Cross-sections, $r(61) = .30, p < .01$. Total Paper-folding correlated only with Total Cross-sections, $r(61) = .21, p < .051$ (bordering
Table 2. Pearson correlation coefficients: Spatial subgroup totals and Total Spatial score

<table>
<thead>
<tr>
<th></th>
<th>Total Puzzles</th>
<th>Total Lego</th>
<th>Total Paper-folding</th>
<th>Total Cross-sections</th>
<th>Total Spatial</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total r</strong></td>
<td>.10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.27</td>
<td>-.01</td>
<td>.29</td>
<td>.59</td>
</tr>
<tr>
<td><strong>Puzzles p</strong></td>
<td>.02&lt;sup&gt;*&lt;/sup&gt;</td>
<td>.48</td>
<td>.01**</td>
<td>.000**</td>
<td></td>
</tr>
<tr>
<td><strong>Total r</strong></td>
<td>.26</td>
<td>.05</td>
<td>.30</td>
<td>.58</td>
<td></td>
</tr>
<tr>
<td><strong>Lego p</strong></td>
<td>.35</td>
<td>.088**</td>
<td>.000**</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total r</strong></td>
<td>-.04</td>
<td>.21</td>
<td>.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Paper-folding p</strong></td>
<td></td>
<td>.05&lt;sup&gt;*&lt;/sup&gt;</td>
<td>.000**</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total r</strong></td>
<td>.59</td>
<td>.81</td>
<td>.000**</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cross-sections p</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total r</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.48</td>
</tr>
<tr>
<td><strong>Spatial p</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Alpha coefficients are listed along diagonal of table.

*<sup>p</sup><.05.

**<sup>p</sup><.01.
on significance). Total Cross-sections, then, was significantly correlated with all three other subgroups. All subgroups were significantly correlated with the Total Spatial score: Total Puzzles, $r(63) = .59, p<.001$; Total Lego, $r(63) = .58, p<.001$; Total Paper-folding, $r(63) = .49, p<.001$; and Total Cross-sections, $r(63) = .81, p<.001$. Thus, the null hypothesis that there would be no significant correlations among the individual spatial items, their subgroup totals, and the Total Spatial score was rejected.

Also indicated in Table 2 (p. 35) are Alpha coefficients for each of the task subgroups and for the total spatial instrument. Low Alpha coefficients for the Puzzles ($\alpha = .10$), Lego ($\alpha = .26$), and Paper-folding ($\alpha = -.04$) subgroups are an indication that any results derived from these three task subgroups must be interpreted cautiously. An item-by-item reliability analysis did indicate that the Alpha coefficient for the Lego subgroup would be increased to $\alpha = .44$ if Lego 4 were deleted. For the Cross-sections subgroup, the Alpha coefficient was .59, a further indication that the Cross-sections tasks were most internally consistent. The entire spatial instrument yielded a moderate Alpha coefficient of .48, which would be increased to .52 if the Paper-folding tasks were deleted. Possible reasons for these low-to-moderate Alpha coefficients, including ceiling effects, small numbers of items, and few types of tasks, will be presented in the Discussion section, along with suggestions for improvement of the instrument.

Table 3 (p. 37) shows Pearson correlation coefficients between chronological age, mental age, and sex (rows of the table) and performance
scores on the four spatial subgroups and Total Spatial score (columns of the table). It can be seen from this table that both mental age and chronological age correlated significantly with all five of the spatial scores. There were no significant correlations between sex and any of the spatial scores. The null hypothesis that there would be no relationship between chronological and mental age and spatial scores was thus rejected, while the hypothesis that there would be no relationship between sex and spatial scores failed to be rejected.

The chief interest of the present investigator lay in whether the performance on certain spatial tasks differed significantly between gifted young children and their chronological- and mental-age mates. Two-way
analyses of variance were performed to test for the main effects of sex and group (gifted, CA match, and MA match) on Total Puzzles, Total Lego, Total Paper-folding, Total Cross-sections, and Total Spatial. There were no significant main effects for sex, nor were there significant interactions between sex and group. The null hypothesis that there would be an effect of sex on spatial performance failed to be rejected. Significant main effects for group were found on Total Cross-sections, $F(2, 57) = 7.28, p<.01$, and Total Spatial, $F(2, 57) = 5.25, p<.01$. These significant main effects were further analyzed by $t$ tests measuring group differences on spatial tasks.

A series of $t$ tests was performed to test for differences between the scores of gifted children and their CA-match and MA-match groups, as well as between the CA-match and MA-match groups themselves, on all 16 tasks individually and on the four subgroup totals and the Total Spatial score. Mean scores by groups are listed in Table 4 (p. 39), and $t$ tests for group differences are reported in Table 5 (p. 40).

On the Total Cross-sections, significant differences were revealed between the gifted ($M = 6.14$) and their CA matches ($M = 8.14$), $t(40) = 3.00, p<.01$, as well as between the CA matches and the MA matches ($M = 6.14$), $t(40) = 3.23, p<.01$. Further, there were significant differences on the Total Spatial score between the gifted ($M = 25.29$) and their CA matches ($M = 28.29$), $t(40) = 2.37, p<.05$, and between the CA match and MA match ($M = 24.76$) groups, $t(40) = 3.31, p<.01$. There were, however, no significant differences between the task performance of the gifted children and their mental-age mates, either on the Cross-sections, Total Spatial, or any other individual task or task subgroup score.
Table 4. Spatial task mean scores by groups

<table>
<thead>
<tr>
<th>Spatial task</th>
<th>Gifted mean</th>
<th>Gifted SD</th>
<th>CA match mean</th>
<th>CA match SD</th>
<th>MA match mean</th>
<th>MA match SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Puzzle 1</td>
<td>1.29(^a)</td>
<td>0.46</td>
<td>1.52</td>
<td>0.51</td>
<td>1.48</td>
<td>0.51</td>
</tr>
<tr>
<td>Puzzle 2</td>
<td>1.90</td>
<td>0.77</td>
<td>1.67</td>
<td>0.66</td>
<td>1.67</td>
<td>0.80</td>
</tr>
<tr>
<td>Puzzle 3</td>
<td>1.19</td>
<td>0.51</td>
<td>1.24</td>
<td>0.54</td>
<td>1.52</td>
<td>0.75</td>
</tr>
<tr>
<td>Puzzle 4</td>
<td>1.52</td>
<td>0.87</td>
<td>2.10</td>
<td>0.94</td>
<td>1.29</td>
<td>0.64</td>
</tr>
<tr>
<td>Lego 1</td>
<td>1.10</td>
<td>0.44</td>
<td>1.19</td>
<td>0.60</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Lego 2</td>
<td>1.24</td>
<td>0.63</td>
<td>1.57</td>
<td>0.93</td>
<td>1.10</td>
<td>0.44</td>
</tr>
<tr>
<td>Lego 3</td>
<td>1.52</td>
<td>0.51</td>
<td>1.67</td>
<td>0.58</td>
<td>1.57</td>
<td>0.51</td>
</tr>
<tr>
<td>Lego 4</td>
<td>1.29</td>
<td>0.46</td>
<td>1.24</td>
<td>0.63</td>
<td>1.38</td>
<td>0.67</td>
</tr>
<tr>
<td>Paper-folding 1</td>
<td>1.61</td>
<td>0.87</td>
<td>1.71</td>
<td>0.90</td>
<td>1.52</td>
<td>0.81</td>
</tr>
<tr>
<td>Paper-folding 2</td>
<td>2.67</td>
<td>0.73</td>
<td>2.86</td>
<td>0.84</td>
<td>2.76</td>
<td>0.63</td>
</tr>
<tr>
<td>Paper-folding 3</td>
<td>1.29</td>
<td>0.64</td>
<td>1.48</td>
<td>0.87</td>
<td>1.29</td>
<td>0.72</td>
</tr>
<tr>
<td>Paper-folding 4</td>
<td>2.33</td>
<td>0.80</td>
<td>1.90</td>
<td>0.77</td>
<td>2.05</td>
<td>0.87</td>
</tr>
<tr>
<td>Cross-section 1</td>
<td>1.29</td>
<td>0.46</td>
<td>1.81</td>
<td>0.87</td>
<td>1.19</td>
<td>0.51</td>
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<tr>
<td>Cross-section 2</td>
<td>1.43</td>
<td>0.60</td>
<td>1.90</td>
<td>0.89</td>
<td>1.57</td>
<td>0.68</td>
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<tr>
<td>Cross-section 3</td>
<td>1.62</td>
<td>0.74</td>
<td>2.33</td>
<td>0.86</td>
<td>1.62</td>
<td>0.74</td>
</tr>
<tr>
<td>Cross-section 4</td>
<td>1.81</td>
<td>0.98</td>
<td>2.10</td>
<td>1.00</td>
<td>1.76</td>
<td>0.89</td>
</tr>
<tr>
<td>Total Puzzles</td>
<td>5.90(^b)</td>
<td>1.55</td>
<td>6.52</td>
<td>1.33</td>
<td>5.95</td>
<td>1.47</td>
</tr>
<tr>
<td>Total Lego</td>
<td>5.14</td>
<td>1.24</td>
<td>5.67</td>
<td>1.39</td>
<td>5.05</td>
<td>1.16</td>
</tr>
<tr>
<td>Total Paper-folding</td>
<td>8.10</td>
<td>1.61</td>
<td>7.95</td>
<td>1.20</td>
<td>7.62</td>
<td>1.69</td>
</tr>
<tr>
<td>Total Cross-sections</td>
<td>6.14</td>
<td>2.03</td>
<td>8.14</td>
<td>2.29</td>
<td>6.14</td>
<td>1.68</td>
</tr>
<tr>
<td>Total Spatial</td>
<td>25.29(^c)</td>
<td>4.58</td>
<td>28.29</td>
<td>3.54</td>
<td>24.76</td>
<td>3.36</td>
</tr>
</tbody>
</table>

Note: CA = chronological age; MA = mental age.

\(^a\)Mean scores on 16 individual tasks have theoretical range of 1 to 3, with 1 representing a perfect score.

\(^b\)Mean scores on 4 task subgroups have theoretical range of 4 to 12, with 4 representing a perfect score.

\(^c\)Mean scores on Total Spatial have theoretical range of 16 to 48, with 16 representing a perfect score.
Table 5. Group differences in spatial task scores: \( t \) test results

<table>
<thead>
<tr>
<th></th>
<th>Gifted versus CA match</th>
<th>Gifted versus MA match</th>
<th>CA match versus MA match</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( t )</td>
<td>( p )</td>
<td>( t )</td>
</tr>
<tr>
<td>Puzzle 1</td>
<td>1.58</td>
<td>.12</td>
<td>1.26</td>
</tr>
<tr>
<td>Puzzle 2</td>
<td>1.08</td>
<td>.29</td>
<td>0.99</td>
</tr>
<tr>
<td>Puzzle 3</td>
<td>0.29</td>
<td>.77</td>
<td>1.68</td>
</tr>
<tr>
<td>Puzzle 4</td>
<td>2.04</td>
<td>.05*</td>
<td>1.01</td>
</tr>
</tbody>
</table>

|                     | \( t \) | \( p \) | \( t \) | \( p \) | \( t \) | \( p \) |
| Lego 1              | 0.59 | .56 | 1.00 | .32 | 1.45 | .16 |
| Lego 2              | 1.37 | .18 | 0.86 | .40 | 2.13 | .04* |
| Lego 3              | 0.85 | .40 | 0.30 | .76 | 0.57 | .57 |
| Lego 4              | 0.28 | .78 | 0.54 | .60 | 0.72 | .48 |
| Paper-folding 1     | 0.35 | .73 | 1.10 | .28 | 0.72 | .48 |
| Paper-folding 2     | 1.00 | .32 | 0.45 | .65 | 0.55 | .58 |
| Paper-folding 3     | 0.80 | .43 | 0.00 | 1.00 | 0.77 | .44 |
| Paper-folding 4     | 1.78 | .08 | 1.11 | .27 | 0.57 | .58 |
| Cross-section 1     | 2.43 | .02* | 0.63 | .53 | 2.80 | .008** |
| Cross-section 2     | 1.95 | .06 | 0.68 | .50 | 1.37 | .18 |
| Cross-section 3     | 2.89 | .006** | 0.00 | 1.00 | 2.89 | .006** |
| Cross-section 4     | 0.94 | .35 | 0.16 | .87 | 1.14 | .26 |
| Total Puzzles       | 1.39 | .17 | 0.10 | .92 | 1.32 | .19 |
| Total Lego          | 1.29 | .20 | 0.26 | .80 | 1.57 | .13 |
| Total Paper-folding | 0.33 | .75 | 0.94 | .36 | 0.74 | .47 |
| Total Cross-sections| 3.00 | .005** | 0.00 | 1.00 | 3.23 | .002** |
| Total Spatial       | 2.37 | .02 | 0.42 | .68 | 3.31 | .002** |

Note: \( \alpha = 40 \) in all \( t \) tests; CA = chronological age; MA = mental age.

*\( p < .05 \).

**\( p < .01 \).
Individual tasks that resulted in significantly better scores earned by both the gifted and their MA matches than by the CA matches were Puzzle 4, Cross-section 1, and Cross-section 3 (see Tables 4 and 5 for means and t test results). Additionally, there was a significant difference between the CA- and MA-match groups in Lego 2, while on Cross-section 2 the difference between the CA matches and the gifted group approached significance, t(40) = 1.95, p<.058. Tables 4 and 5 also reveal that in the total Lego task subgroups, the gifted performed more like their MA matches than their CA matches, though there were no significant differences between any of the groups on these tasks.

The null hypothesis that there would be no differences between the performance of the gifted children and their chronological-age mates, nor between the chronological-age mates and the mental-age mates on spatial performance was rejected for Total Cross-sections, Total Spatial, Puzzle 4, Lego 2, and Cross-sections 1, 2, and 3. The null hypothesis that there would be no difference in spatial performance between the gifted children and their mental-age mates failed to be rejected.

Examination of the mean scores achieved by the three groups (Table 4) reveals some other interesting, if nonsignificant, data. The finding of no significant differences between the gifted children and their MA matches is further illuminated by the finding that on 7 of the 16 individual items, the gifted children either performed as well as, or better than (though not significantly so), their mental-age mates. Also, there were 4 items on which the CA matches did as well as, or better than (though not significantly so), the gifted group (Puzzle 2, Lego 4, Paper-folding 1, and
Paper-folding 4). On 3 of these 4 items (all but Paper-folding 1), the CA matches also performed as well as, or better than (though not significantly so), the MA match group—children who differ in average chronological age by more than two years.

Partial correlations were performed to further investigate the effect of chronological age and mental age on subgroup totals and the Total Spatial score. With the effect of mental age removed, chronological age was found to significantly correlate, $r(60) = .26$, $p<.02$, only with the Total Paper-folding score. Controlling for chronological age, however, mental age significantly correlated with Total Puzzles, $r(60) = .28$, $p<.02$; Total Lego, $r(60) = .33$, $p<.01$; Total Cross-sections, $r(60) = .52$, $p<.001$; and Total Spatial, $r(60) = .53$, $p<.001$.

In addition to examining whether gifted children differed from their chronological- and mental-age matches in spatial performance, the present study also investigated whether the sample of children progressed in a stage-like manner in their spatial competency. The response choices had been designed in such a manner as to afford an intermediate amount of point credit for a response representing an intermediate stage of spatial development. To determine whether children's responses conformed to such a pattern, the following statistical approach was used: First, it was decided to compare only the CA-match group with the MA-match group, since this comparison most clearly represented a developmental transition. The gifted children were excluded because it could not be determined where Piagetian developmental theory would place them—with their chronological-age mates, according to their age, or with their mental-age mates,
according to their psychometric (and in this research, their spatial) ability.

Previous t tests had determined that the MA-match children did perform significantly better than the CA matches on the Total Cross-sections and the Total Spatial. Inspection of Tables 4 and 5 will indicate that the MA-matches also outperformed the younger group on Total Lego, Total Puzzles, and Total Paper-folding, though differences did not reach significance. These results, differentiating the older children from the younger, could have arisen if the older children simply chose the one correct answer more often. By themselves, these results don't necessarily imply a stage-like progression, according to which the older children who made errors were more likely than the younger children who made errors to choose the intermediate (two point) response than the least correct (three point) response. To determine if this were the case, chi-square tests were performed comparing the pattern of the MA-match group and the CA-match group in their choice of incorrect answers on the spatial subgroup scores and the Spatial Total score. Results of these analyses are outlined in Appendix G. Chi-square tests demonstrated that the MA-match group was significantly more likely than the CA-match group to choose the intermediate response over the least correct response in three cases: Total Lego, \( \chi^2(1, n = 43) = 4.36, p<.05 \); Total Cross-sections, \( \chi^2(1, n = 84) = 9.59, p<.005 \); and Spatial Total, \( \chi^2(1, n = 290), p<.05 \). For these spatial tasks, the null hypothesis that no stage-like progression exists in spatial performance was rejected.
DISCUSSION

Addressing the question of whether more than one spatial ability is being tapped by the spatial instrument used in the present study, results show that the Puzzles, Lego, and Cross-sections subgroups are significantly correlated in the abilities being measured. The Paper-folding task subgroup, on the other hand, correlated only with the Cross-sections task subgroup, and will be shown later in the discussion to behave differently in other ways as well.

It would exceed the scope of the present study to extract from the results any all-encompassing statements as to the unity of spatial ability. Intercorrelations among individual spatial tasks (Appendix F) and Alpha coefficients for task subgroups (Table 3, p. 37) indicate that internal consistency varied considerably from one task subgroup to the next, with Paper-folding least consistent and Cross-sections most consistent. It is assumed that the ceiling effect evident in the Puzzles and Lego subgroups (see mean scores, Table 4, p. 39) influenced these internal consistency measures. However, the Paper-folding and Cross-sections tasks, while similar in overall difficulty, were at the extremes of internal consistency. The Paper-folding tasks operated largely independently of one another, while the Cross-sections tasks displayed a moderate Alpha coefficient of .59. The moderate ($\alpha = .48$) Alpha coefficient yielded by the total spatial instrument suggests caution in the interpretation of results.

In addition to yielding an extremely low Alpha coefficient ($\alpha = -.40$), the Paper-folding task subgroup also failed to correlate with the Puzzles
and Lego subgroups. Deletion of the Paper-folding tasks from the total spatial instrument would have increased the Alpha coefficient of the instrument from .48 to .52. It is possible that, although all spatial tasks were intended as mental rotation tasks, that mental rotation was not the only way to solve them. Certainly the mental manipulation involved in rotating a figure as a whole is a little different than mentally unfolding in several directions the various sides of a cardboard geometric figure. Such a task could conceivably be solved by noting which sides of the figure are contiguous with one another. The research of Shepherd and Feng (1972), however, seems to indicate that, for adults at least, such problems are solved by mentally unfolding one side after another.

Table 3 (p. 37) reports the correlations of the spatial tasks with certain demographic variables. All spatial subgroups, as well as the Spatial Total score, correlated with both chronological and mental age, p<.05. This result is not surprising, since even within the sample consisting of 21 gifted and 42 average-ability children, it is still the case that mental and chronological age tend to increase together, and it might be reasonably expected that children would become more competent at nearly every kind of task, including spatial tasks, as they increased in age.

In this respect, the partial correlations were both more interesting and more informative. As stated in the Results section, chronological age correlated significantly only with Total Paper-folding, r(60) = -.26, p<.05, when mental age was "partialed out." In the Paper-folding subgroup, the tasks seemed to demand some competence that added years of chronological age provided, regardless of any increase in mental age.
On the other hand, with the effect of chronological age partialled out, mental age correlated significantly with Total Puzzles, $r(60) = -.28, p<.05$; Total Lego, $r(60) = -.33, p<.005$; Total Cross-sections, $r(60) = -.52, p<.000$; and Total Spatial, $r(60) = -.52, p<.000$; but did not correlate significantly with Total Paper-folding. Again, it appears that the Paper-folding subgroup is in some way at variance with the other tasks. Task difficulty seems unlikely to be the sole explanation, since Paper-folding was neither the easiest nor the most difficult task in terms of average scores achieved. Since chronological age was a crucial component in Paper-folding skill, the possibility that actual experience-over-time had some effect can't be dismissed.

There were no significant correlations between sex and the spatial subgroups or the Spatial Total. Analyses of variance examining the effects of group and sex on spatial scores also failed to show a significant effect of sex. Since the literature reports that sex differences in spatial ability do not generally appear until puberty, the results of the present research are not unexpected. However, it is worth noting that Guay and McDaniel (1977) found male superiority in the higher-level spatial abilities as early as second grade. The children in the present sample ranged from preschool to the fifth grade, and, as stated, no sex differences were found, even on a complex spatial task such as the mental cross-sectioning of a geometric solid.

Turning to the question of group (gifted, CA-match, and MA-match) differences in spatial performance, results support the evidence that children who are psychometrically gifted are also above average in terms
of certain spatial abilities. These findings generally concur with those of Dodwell (1963), Dudek, Lester, Goldberg, and Dyer (1969), DeVries (1974), and, to some extent, Lehman and Erdwins (1982). Direct comparisons must be made with caution, since IQ measures, children's ages, IQ ranges, and spatial tasks vary from one study to the next.

It is interesting to speculate as to the reasons why the Paper-folding task subgroup comprised a statistically unique situation within the total spatial instrument. The Paper-folding subgroup score was the only one to yield a significant first-order correlation with chronological age, with the effects of mental age removed. Correspondingly, it was the only task subgroup upon which the performance of the gifted children resembled that of their chronological-age mates more than that of their mental-age mates. It seems unlikely that children would have had more repeated experiences with paper-folding than with turning puzzle pieces to fit or with putting Lego constructions together. This possibility must be considered, however, along with the possibility that the other three tasks are more likely to be solved with the aid of mental processes related to psychometric giftedness. The latter possibility seems most reasonable in the case of the Cross-sections task subgroup, which yielded the greatest significant difference in favor of the gifted and their mental-age mates. The Cross-sections tasks were more difficult than the Lego and Puzzle tasks (as determined by mean scores achieved), and they involve a more complex mental manipulation. It is possible that these tasks involve more elements of problem-solving, and less of simple visualization, and are, therefore, more affected by those problem-solving skills measured by the
Stanford-Binet IQ scale.

Those individual tasks (Puzzle 2, Lego 4, Paper-folding 4) on which the gifted and their mental-age mates actually performed the same as, or less well (though not significantly so) than the chronological-age matches present a puzzling situation. It may be that there is some factor in these items which caused the gifted children and the MA matches to apply problem-solving skills in inappropriate ways, ways which were not needed in the solution of these particular problems. Or there may be some problems that are best solved with a visualization technique rather than a problem-solving technique, and younger, average-ability children may be more prone to solve spatial problems by simple visualization.

The final step in the analysis of the results was the series of Chi-square tests determining whether there was evidence for a stage-like progression in the responses of the CA- and MA-match groups. It was found that for Total Lego, Total Cross-sections, and Total Spatial, the older children, whose overall spatial performance exceeded that of the younger children, were also more likely to choose the intermediate response than the least-correct response when they failed to choose the correct response. These results reinforce the Piagetian notion that, in at least some areas of spatial development, children develop in a step-wise progression, at first failing to grasp even topological features, then learning to recognize these cues (contiguity, enclosure, etc.), and finally combining these topological cues with the ability to mentally rotate or manipulate an object in space. It is interesting that the Total Cross-sections subgroup of tasks was most successful in yielding a stage-like progression of
responses ($x^2[1,n = 84] = 9.59, p<.005$), since the Cross-sections response choices were taken most directly from Piaget and Inhelder's (1956) description of children's actual drawings of cross-sections tasks. This result also gives some support to the acceptability of using children's drawings (Dean, 1982) as a measure of their mental imagery. In the case of the Lego subgroup, the results give support to the topological versus Euclidean, or projective, approach to spatial problem-solving, since in each of the Lego tasks the intermediate response choice was the mirror image of the correct response choice. Hence, topological cues alone would not suffice for the solution of the problem. Actual mental rotation, with the consequent left-right reversal, is required. The child must recognize "... the relationship between the mobile object and its successive positions ..." (Piaget and Inhelder, 1956, p. 476).

An expanded version of the present research could be designed to (a) reduce or eliminate the "ceiling effect" most evident in the Puzzles and Lego subgroups, (b) expand the number of tasks within each subgroup, (c) include more types of spatial tasks, (d) test for reliability, (e) extend the research design longitudinally, (f) measure the effects of training, and (g) re-examine the stage-like development of children's spatial competence. The next few paragraphs will elaborate upon each of these suggested revisions in turn.

A striking feature of the Puzzles and the Lego subgroups was the ability of even the youngest, average-ability children to perform so well, as indicated by the mean scores reported in Table 4. The strong probability that a ceiling effect on these tasks has limited the ability of
the tasks to discriminate among subjects suggests that future revisions of this spatial instrument should include more difficult tasks. Tasks could be made harder simply by making the model and response forms more complex, or by varying the degree of rotation required to create the mental "match" representing the correct response. The inclusion of more difficult items would increase the range of scores achieved, thus increasing the possibility of significant group differences and inter-task correlations. Expanding the number of tasks within each task subgroup, along with increasing task difficulty, would allow for a greater range of responses by the total subject sample. A greater number of tasks within subgroups would allow the experimenter greater opportunity to select out tasks within subgroups that intercorrelated significantly with one another, resulting in the refinement of the spatial instrument.

Including more types of spatial tasks in the instrument is desirable for many reasons. The question of the unity of spatial ability would be addressed more completely. Group differences among the gifted and their CA and MA matches could be examined across a wider variety of spatial tasks. If the results of the present study are an indication, some tasks will be related more to mental age, while others will correlate more highly with chronological age. A useful guide to spatial task categories appropriate for inclusion in an expanded spatial instrument would be Eliot's (1980) outline of 12 spatial task categories, ranging from simple matching and recognition tasks to complex problem-solving items. Eliot's outline is a comprehensive one, and using it as a guide to task selection would result in a spatial instrument allowing more direct comparison
to much of the spatial literature. The inclusion of more types of tasks across a greater range of complexity would allow a greater opportunity to reveal sex differences in spatial performance along those lines suggested by Guay and McDaniel (1977).

Increasing numbers of tasks within subgroups, expanding numbers of subgroups (task types), and increasing the difficulty of task items are all techniques to increase the value of the Alpha coefficient, or the measure of internal consistency, of the spatial instrument (Nunnally, 1967). These statistical techniques to improve the instrument should, of course, be combined with a subsequent item analysis to determine which items do indeed discriminate in valid and reliable ways.

Test-retest reliability should also be measured by readministering the same spatial instrument within two to three weeks following the first administration.

A longitudinal extension of the present research design would provide useful data on the seldom-studied question of stability of spatial ability in young children. If spatial ability is a stable trait, early identification of extremes of ability might indicate more appropriate educational efforts, both to develop spatial giftedness and to alleviate problems in children for whom spatial concepts prove an obstacle. Further, the longitudinal design is essential in tracing the development of sex differences in spatial ability.

Based upon the results of an expanded spatial instrument, a spatial problem-solving curriculum could be developed and implemented. Employing appropriate controls for maturation, an alternate form of the spatial
instrument could be administered as a post-test, thus measuring the effects of training. The spatial literature includes few studies on the effects of spatial training (Fennema, 1981), and such studies on the pre-school child, whether gifted or average-ability, are fewer still.

Concerning the stage development of spatial skills, it would seem that children learn to solve at least some spatial problems (Lego and Cross-sections) in a stage-like manner. In any future modification of the present spatial instrument, it would be useful to reexamine the response choices for the Puzzles and Paper-folding tasks and attempt to alter the foils so as to yield a stage-like progression in the response to these tasks as well. Increasing the task difficulty of the Puzzles and Paper-folding tasks might contribute to this end, since it would force more subjects into the "incorrect response" category, thus increasing degrees of freedom associated with the Chi-square tests. Response foils should also be reexamined to determine whether the intermediate foils did indeed meet the Piagetian criterion of topological correctness.

The results of the present study indicate that at least some spatial abilities are correlated more with mental age than with chronological age, and that educational curricula aimed at high-ability youngsters could include an advanced spatial learning component. Sex differences would apparently not constitute an educational consideration, although it would be useful to investigate whether increasing the difficulty of the tasks and extending the research longitudinally would introduce such differences.

Finally, it would seem that children learn to solve at least some spatial problems in a stage-like manner. Further research might outline
more clearly stage-like steps in the learning of other spatial concepts as well. Educational materials and activities could be designed with this progression in mind, directing earliest efforts toward topological concepts, such as continuity and enclosure, and subsequent efforts towards more projective skills, such as the mental manipulation of objects in space and the assuming of the physical viewpoint of another person.
REFERENCES


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Appreciation is also due the excellent staff of the Child Development Laboratory Schools, who were unfailingly cooperative and supportive, as were the administrator, office staff, and teachers of Gilbert Elementary School. With special affection I thank all the children who so willingly participated in my research.

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Last, but certainly not least, I want to thank my husband, Dave, and my two children, Nathan and Erin, who consistently remind me what everything is really for.
APPENDIX A.

PUZZLE TASKS: TWO SAMPLE ITEMS AND FOUR TEST ITEMS
The Puzzle tasks on the following six pages are all reproduced according to their actual size. The white background cardboards against which the yellow puzzle pieces were displayed are not outlined in order to save space on the page and permit the presentation of the puzzle pieces according to their actual size. The background cardboards measured 18 cm by 23.5 cm. Point values of each of the three response choices are indicated for the four test items.
Puzzle tasks:

Sample item 1.

Model form and response choices shown actual size.
Puzzle tasks:
Sample item 2.

Model form and response choices shown actual size.
Puzzle 1.

Model form and response choices shown actual size.

3-point answer
2-point answer
1-point answer
Puzzle 2.

Model form and response choices shown actual size.
Puzzle 3.

Model form and response choices shown actual size.

1-point answer

2-point answer

3-point answer
Puzzle 4.

Model form and response choices shown actual size.

3-point answer

1-point answer

2-point answer
APPENDIX B.

LEGO TASKS: TWO SAMPLE ITEMS AND FOUR TEST ITEMS
The Lego tasks on the following six pages are all reproduced according to their actual size as shown from above. The key below indicates the height in number of Lego "bricks" of the Lego constructions. Each brick measures approximately 1 cm in height. The drawings do not show the raised round circles characteristic of all Lego bricks.

One Lego brick high

Two Lego bricks high

Three Lego bricks high

The white background cardboards against which all of the Lego constructions were displayed are not outlined in order to save space and allow the presentation of the Lego constructions according to their actual size. Background cardboard measured 18 cm by 23.5 cm. Point values of the three response choices are indicated for the four test items.
Lego tasks:
Sample Item 1.

Model form and response choices are shown actual size.
Lego tasks:

Sample item 2.

Model form and response choices are shown actual size.
Lego 1.

3.2 cm

Model form and response choices are shown actual size.

1-point answer

3-point answer

2-point answer
Lego 2.

Model form and response choices are shown actual size.
Lego 3.

Model form and response choices are shown actual size.
Lego 4.

Model form and response choices are shown actual size.
APPENDIX C.

PAPER-FOLDING TASKS: TWO SAMPLE ITEMS AND FOUR TEST ITEMS
The model forms for the Paper-folding tasks on the next six pages are drawn according to their actual size, while the response choices are reduced to 1/3 their actual size. The yellow background cardboards against which the response choices were displayed are not outlined in order to save space on the page and allow the presentation of the unfolded paper forms at 1/3 their actual size. The yellow background cardboard measured 25.4 cm by 51 cm. Point values of each of the three response choices are indicated for the four test items.
Paper-folding tasks:

Sample item 1.

Model form shown approximately actual size.
Response choices reduced to 1/3 actual size.
Paper-folding tasks:

Sample item 2.

Form folds to a closed "pup-tent."

Model form shown approximately actual size.
Response choices reduced to 1/3 actual size.
Paper-folding 1.

Visible seam.

Form is a closed cylinder.

Model form is shown approximately actual size.
Response forms are reduced to 1/3 actual size.

3-point response

2-point response

1-point response
Paper-folding 2.

Model form is a cube.

Model form is shown approximately actual size.
Response choices are reduced to 1/3 actual size.
Paper-folding 3.

Model form is closed pyramid with square base.

Model form is shown approximately actual size.

Response forms are reduced to 1/3 actual size.

2-point answer

1-point answer

Yellow background

3-point answer
Paper-folding 4.

Model form is a closed rectangle.

Model form is shown approximately actual size.

Response choices are reduced to 1/3 actual size.
APPENDIX D.

CROSS-SECTIONS TASKS: TWO SAMPLE ITEMS

AND FOUR TEST ITEMS
The Cross-sections items on the following six pages are all drawn according to their actual size. The white cardboard backgrounds on which the response choices were drawn are not outlined in order to save space on the page and permit the presentation of the response choices according to their actual size. The background cardboards measured 18 cm by 23.5 cm. Point values of each of the three response choices are indicated for the four test items.
Cross-sections tasks:

Sample item 1.

Black line denoting cross-section.

Model form is a solid wooden sphere.

Model form and response choices shown actual size.
Cross-sections tasks:

Sample item 2.

Black line denoting cross-section.

Model form is a solid wooden cylinder.

Model form and response choices are shown actual size.
Cross-section 1.

Sample item 2.

Black line denoting cross-section.

Model form is a solid wooden rectangular block.

Model form and response choices are shown actual size.

2-point answer

3-point answer

1-point answer
Cross-section 2.

Black line demoting cross-section.

Model form is a solid wooden cone.

Model form and response choices are shown actual size.

2-point answer

1-point answer

3-point answer
Cross-section 3.

Model form is a solid wooden three-sided pyramid.

Model form and response choices are shown actual size.
Cross-section 4.

Model form is a solid wooden cone.

Model form and response choices are shown actual size.
APPENDIX E.

VERBAL INSTRUCTIONS AND SCORE SHEET FOR SPATIAL TASKS
I'm going to show you some puzzles, but these puzzles are just for looking at. You won't need to touch them at all. I'll hold them so you can see them. Look, here is a puzzle piece and here are 3 places it might fit, but it will really only fit in one place. You can see I'll have to turn the piece to make it fit somewhere. I'll turn the piece. Now, does it fit here or here or here?

Repeat.

Now look. Here is another piece and 3 places it might fit. But see? This piece is glued down. You will have to pretend to turn it in your mind. You'll have to imagine how it will look after you turn it, so that you can see where it will fit. So if you turn the piece, where will it fit? Will it fit here or here or here?

This piece is glued down too. You'll have to imagine how it will look after you turn it so that you can see where it will fit. So if you turn the piece where will it fit? Will it fit here or here or here?

Repeat.

Repeat.

Now look. Here are some little Lego blocks. These 3 are glued down and this one I can turn. If I turn this one it will look just like one of these, but only one of them. I'll turn it and you decide. Does it match this one or this one or this one?

Repeat.

Now see these Lego pieces. This one is glued down too, just like these three. You will need to pretend to turn it in your mind. You will have to imagine how it will look after you turn it so that you can decide which one it matches. So if you turn the piece will it match this one or this one or this one?

This piece is glued down too. You'll have to imagine how it will look after you turn it so that you can see where it will match. So if you turn the piece, which one will it match? This one or this one or this one?

Repeat.

Repeat.
Now look here. This a different kind of thing. It's a cardboard shape that I can unfold. When it's folded it looks like this. But when it's unfolded it will lie flat like this, see? Now when I unfold it, it will match one of these 3 unfolded shapes, but only one. Will it match this one or this one or this one?

Repeat.

Now look at this cardboard shape. It's all glued together so I can't unfold it. You will have to pretend to unfold it in your mind. You'll have to imagine how it will look after you unfold it so you can see which one of these it will match. So if you unfold it will it match this one or this one or this one?

This shape is all glued together too. You'll have to imagine how it will look after you unfold it so that you can tell which one of these it will match. So if you unfolded it, would it match this one or this one or this one?

Repeat.

Repeat.

Repeat.

Here is one last set of things. Look, here is a block of wood. See, it has a black line around it. Now I'm going to take a knife and pretend to cut the block apart on this line. See, I have a block just like this one that's really cut apart. If I really cut it apart it would break open like this, wouldn't it? See, this part I've painted black is where it would be cut by the knife. Now this cut part would match one of these 3 black shapes, but only one. Would it match this one or this one or this one?

Repeat, except for first sentence above.

Now look at this block of wood. It has a black line to cut on too. But I don't have one like this one that's really cut apart. You'll have to pretend to cut it apart in your mind. You'll have to imagine how the cut part would look if you really cut it apart with the knife. (Make break-open motion with first one only.) If I really cut it apart, would the cut part look like this or this or this?

Here is another block of wood with a black line. You'll have to imagine how the cut part would look if I really cut the block apart. If I really cut the block apart, would the cut part look like this or this or this?
APPENDIX F.
PEARSON CORRELATION COEFFICIENTS: INDIVIDUAL SPATIAL TASKS, SUBGROUP TOTALS, AND TOTAL SPATIAL
Table F.1. Individual spatial tasks, subgroup totals, and total spatial

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APPENDIX G.

CHI-SQUARE TESTS FOR DIFFERENCES IN FREQUENCY OF
INCORRECT RESPONSES ON SPATIAL TASKS:
CA (CHRONOLOGICAL AGE) VERSUS MA (MENTAL AGE) MATCH GROUPS
Total Puzzles

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\[\chi^2(1, n = 72) = 0.16\]
\[p > .05\]

Total Lego

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</tbody>
</table>

\[\chi^2(1, n = 43) = 4.36\]
\[p < .05\]

Total Paper-folding

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</table>

\[\chi^2(1, n = 91) = 0.17\]
\[p > .05\]

Total Cross-sections

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\[\chi^2(1, n = 84) = 9.59\]
\[p < .005\]

Total Spatial

<table>
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</table>

\[\chi^2(1, n = 290) = 5.15\]
\[p < .05\]