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ABSTRACT

This study investigated the nature of spatial ability, as measured by four instruments based on spatial orientation and visualization, and its relationship to the mathematical performance of elementary school pupils. Participating in the study were 127 elementary school students, 72 boys and 55 girls, ages 10 to 11 years. Spatial ability was measured by the Spatial Relations-Orientation Test and the Spatial Visualization Test, each having two- and three-dimensional aspects. Mathematics performance was assessed by the Comprehensive Test of Basic Skills, and included mathematical computation, concepts, and application. The findings of a factor analysis on the Spatial Relations-Orientation Test and the Spatial Visualization Test indicated that spatial ability was best defined by a unitary factor. Boys did not perform significantly better than the girls on the four individual spatial tasks. There was a significant positive relationship between spatial ability and mathematical performance. The spatial factor score was a significant predictor of mathematics performance. There were no significant gender-related differences in the relationship between spatial ability and mathematical performance. (Contains 21 references.) (KB)

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SPATIAL ABILITY AND MATHEMATICAL PERFORMANCE : GENDER DIFFERENCES IN AN ELEMENTARY SCHOOL

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Abstract

The purpose of this study was to investigate the nature of spatial ability as measured by four instruments based on spatial orientation and visualisation, and its relationship to the mathematical performance of elementary school pupils. Research reviews indicate that such relationships have shown inconclusive and even conflicting results varying with respect to age and sex differences. In this study 127 elementary school pupils, 72 boys and 55 girls were given 4 spatial relations tasks in their two and three dimensionalities. Their performance in mathematical computation, concepts and application were examined and correlated with their spatial ability. Results showed that spatial ability is best defined by a unitary factor. There is some gender difference in spatial ability with different manifestations for both boys and girls. However, the boys were found not to be significantly better than the girls in the four spatial tasks. A significant positive relationship was found to exist between spatial ability and mathematical performance. There are no significant gender-related differences in the relationship between spatial ability and mathematical performance. Several important educational implications from this study are highlighted.

In the 1960s, many psychometricians believed that one mode of thought underlies both mathematical and spatial reasoning; some proposed that spatial ability enables those who possess it to reason differently and more effectively. (Smith, 1964; Witkin et al., 1962; Battista, 1994). However, not all researchers agree on these views. Spatial skills may just be another cognitive skill and Howard Gardner (1983) articulated in the notion of a single "logico-mathematical" ability which is the ability to handle long chains of reasoning and to discover analogies between mathematical abstractions. Interest in the nature of the relationship between spatial ability and mathematical performance has led to further research. The results are often contrasting, both in the approximate size of correlations found and the conclusions drawn from them (Becker and Hedges, 1984).

In a review of mathematical and spatial studies, Smith (1964) concluded that "there are several studies which indicate consistently that spatial ability is important in tests which are genuinely mathematical as distinct from those which involve purely mechanical or computational processes". (pg 127). He cited evidence indicating that verbal and mathematical abilities were independent and state that high spatial rather than high verbal ability is a prerequisite for success in advanced mathematical and technical courses. Likewise, Aiken (1973) concluded that spatial-perceptual ability was one of the most salient mathematical factors found in the various studies.

Much of the thinking required in higher mathematics is spatial in nature. Einstein commented that his elements of thought were not words but "certain signs and more or less clear images which can be voluntarily reproduced or combined" (Gardner, 1983, p 190). Mathematics educators have suggested that spatial ability and visual imagery play vital roles in mathematical thinking. Positive correlations have been found between spatial ability and mathematics performance at all grade levels in solving problems that involve geometry.(Fennema & Sherman, 1977) and Hershhkowitz (1989) has outlined the role of visualization in the development of a student's conceptualisation of a geometric idea. Visual thinking is utilised by many students in representing and operating on concepts that do not inherently contain a spatial aspect . Heavy reliance on visual representations of mathematical ideas might be especially important at the elementary school level since young children rely more heavily on imagery than do adults. (Stigler et al, 1990).

Fennema (1974) states that the relationship between mathematics and spatial ability is "logically evident" (p 34). Concerning spatial representations used in mathematics, Fennema commented that "not only are spatial visualisation components an integral part of the structure of mathematics, spatial representations are being increasingly included in the teaching of mathematics…most concrete and pictorial representations of arithmetical, geometrical and algebraic ideas appear to be heavily reliant on spatial attributes." (p 36). However, when students are using a problem-solving process that emphasised the use of spatial visualisation, those who had high spatial visualisation skill solved no more problems than students who had low spatial visualisation skill. It is concluded that students who process mathematical information by verbal logical means outperform students who process this information visually as the use of imagery in mathematical thinking can cause difficulties.

Wheatley (1990) reported that although the fifth-grade girls with low spatial ability that they interviewed performed well in school mathematics, their understanding of multiplication and division was instrumental, whereas the high spatial girls' understanding was more relational. Similarly, Tarte (1990) suggested that tenth grade students who scored high on spatial orientation were better able to understand non-geometric problems and to link them to previous work than were students who scored low in spatial orientation. The ability to visualise abstract mathematical relationships and the ability for spatial concepts need not be necessary components in the structure of mathematical ability. Two different modes of thought, verbal-logical and visual-pictorial may be used in mathematical problem solving.

From his study, Moses (1977) attempted to determine the relationship of spatial ability and mathematical problem solving performance. She found that spatial ability was a good predictor of problem solving performance and that an individual with high spatial ability did not necessarily use visual solution processes while solving a mathematical problem. Gardner (1985) argued that spatial ability is one of the several "relatively autonomous human intellectual competences" which he calls "human intelligences". Spatial thinking is essential to scientific thought; it is used to represent and manipulate information in learning and problem solving. His portrayal of the mathematical-logical intelligences as the ability to create long chains of reasoning about mathematical objects provides a sharp contrast to characterisations of mathematics as essentially spatial. There is reason to believe that spatial ability is important in students' construction and use of mathematical concepts, even non-geometric ones but the role that such thinking plays in this construction is elusive and, even in geometry, multifaceted.

GENDER DIFFERENCES

Gender differences in spatial skills have long been documented, though evidence is not conclusive. The relationship between spatial and mathematical ability appeared to be gender-specific (Sherman, 1967). In one study Weiner (1984) found that the space-math relationship might be stronger for girls than for boys but Connor and Serbin (1985) reported otherwise. Theorists have suggested that the existence of sex differences in spatial ability is a result of genetic factors, learning opportunities, differences in child-rearing, and social expectancies (Elliot & Fralley, 1976; Sherman 1967). Given the heavy demand on representation and imagery in mathematics education it is implied that spatial ability can be an important function of mathematical performance. Also if visual representation requires spatial ability beyond the capacity of the students, then there will be a mismatch between what the teacher intends to convey and what the student actually learns.

Research on gender differences in mathematics has often been based on Sherman's (1967) conjecture that the lack of development of spatial ability in women caused commensurate lacks in other cognitive areas, including mathematical ability. Some educators have found Sherman's hypothesis plausible (Ethington and Wolfle, 1984; Fennema, 1985). Studies of general abilities and of general mathematical ability, though not centered on gender differences, have produced gender specific statistics. For example, Ethington and Wolfle (1984) used path analysis with High School and Beyond data, and concluded that spatial ability had an indirect effect, through gender, on mathematical performance.

In several other pieces of research, mathematical performance generally correlates with spatial visualisation in the range of .30 to .60 and males' spatial scores have consistently been found to be higher than females' (Battista 1990; Ben-Chiam et al, 1988; Tarte, 1990). Gender differences in favour of males appear in a broad spectrum of tasks and situations. The most common mathematical area for gender difference researchers has been in mathematical problem solving (Schonberger,1979). As the ability to solve problems is the crucial determinant of success not only for research mathematicians but also for those employed in mathematical occupations, this measured deficit in female performance is high on the agenda of those interested in gender equity. Males do very much better than females in problem solving and the largest differences were on problems for which diagrams were not provided

In Singapore there has been an increase in emphasis on visual thinking in the mathematics curriculum. One formal topic involving spatial relations in two and three dimensions is included in each level from grade one to six. In the unit on fractions, teachers are encouraged to use the concrete/pictorial representation to help children in their understanding of the concept. In solving mathematical problems, the part-whole model is used similar to the concrete representation of algebra. The process involves visualising the question and translating it in the concrete form.

This study hopes to investigate the following questions:

1. Is spatial ability separated into two major factors of spatial relations-orientation and visualisation.
2. Are there gender-related differences in spatial ability.
3. Is there a relationship between spatial ability and mathematical computation, concepts, application and grades.
4. Are there gender-related differences in the relationships between spatial ability and the measures of mathematical performance.

METHOD AND INSTRUMENTS

The sample for the study consisted of 127 elementary fifth grade boys and girls, aged between 10 and 11 from three classes randomly selected from an elementary school. The mathematics curriculum is the same for all the classes and they were taught topics like Whole and Decimal Numbers, Fractions, Word Problems, Area and Perimeter, Angles, Solids and Nets, Ratio and Rate and Speed.

Spatial ability is measured by Spatial Relations-Orientation Test (SR-O) and the Spatial Visualization Test (Vz). Each of these tests has the two and three dimensional aspects. The mathematics performance is based on the mathematics section of the Comprehensive Test of Basic Skills. (CTBS). It includes mathematical computations, concepts and application.

RESULTS

Four hypotheses based on the above questions were tested.

Hypothesis 1
It was hypothesised that spatial ability is separated into two major areas: spatial relations-orientation and spatial visualisation. Results from factor analysis indicated that the spatial ability tests in the present study had one underlying factor.

Hypothesis 2
There are no gender-related differences in spatial ability. Results from Table 1 indicated that there was no significant difference between the boys and girls on any of the individual spatial tests. Boys obtained slightly higher scores than girls. There was also no significant difference in the overall magnitude of the factor loadings for boys and girls from a factor analysis of the data.

Hypothesis 3
It was hypothesised that a significant positive relationship exists between spatial ability and the following measures of mathematical performance : computations, concepts, application and overall grades. Factor analyses and t-tests (Tables 2, 3 and 4) indicate that there is a significant positive relationship between the spatial ability and mathematical performance variables. The spatial factor score was a significant predictor of the mathematical performance measures.

Hypothesis 4
There are no gender-related differences in the relationships between spatial ability and the measures of mathematical performance. Factor analyses and multiple regression analyses (Tables 5 and 6) showed that there are no significant differences between the boys and girls. Results indicate that all four of the mathematical performance measures had a significant improvement in prediction when sex was included as a variable. Sex of the person predicted all aspects of mathematical performance above spatial ability. Further analyses (Tables 7 and 8) using the six spatial variables instead of the spatial factor show similar results of the regression analysis which used the spatial factor scores. Girls on the whole tend to get higher mathematical performance scores than would have been predicted by the spatial test scores. The sex variable, however is not a significant predictor of the mathematical performance, except for the grades variable.

DISCUSSION

This study indicates the emergence of the spatial factor variable within mathematical performance. There is also a significant positive relationship between spatial ability and various measures of mathematical performance. The applications and concepts tests contain various items with visual representations. One explanation for the positive relationship lies in the manner in which mathematical ideas are acquired. If visual representations were used during mathematics instruction, the students' spatial ability can have a strong influence on mathematical understanding. Piaget (1967) indicated that the child could progress at various rates through the four stages of cognitive development and three stages of spatial development. Mathematical and spatial skills appear to develop concurrently.

The pattern of gender-related differences in cognitive abilities appears to have changed during the past decades. Cultural factors as well as training programmes could have influenced spatial ability and mathematics performance. The enhancement of one ability can have the same effect on the other. However, an effort should be made to diagnose each student for individual weaknesses in spatial ability and appropriate spatial instruction be provided.

Visual skills appear to have an important role in mathematical performance. Fennema (1974) noted that it is when mathematical ideas are first introduced that spatial ability is important. Many of the basic concepts of mathematics are presented with the aid of visual materials, especially in the lower elementary grades. Without adequate spatial ability, the understanding of the basic mathematical ideas would be restricted and subsequent mathematical learning would be hindered.

Spatial thinking skills should be included and infused into the mathematical curriculum. Visual representations such as diagrams, pictures, charts, tables and graphs are used in mathematics instruction to help understanding. Spatial instruction however, can be provided in the same way as reading instructions and in this manner, ameliorate and overcome deficient spatial ability and visual literacy. The role of spatial training in the school curriculum can be explored in the area of curriculum research and development. The visual education of students remains an important part of the total school curriculum.

The results of the present study indicate a need to explore the interrelationships between verbal and visual processing. For instructional materials to be effectively conveyed, verbal skills or ability is essential. Students construct robust concepts through a meaningful synthesis of diagrams and visual images on the one hand and through verbal definitions and analyses on the other.

Computers, which have gained much emphasis in recent years and more so in the years to come, can provide a supportive environment for the learning of spatial skills or other mathematical skills. Much can be done to ascertain the importance of such tools in the learning of spatial skills and whether mediation through such tools can serve as a catalyst for the development of classroom cultures in which both teachers and students expand their learning of mathematics.

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Variable	BOYS Mean	SD	GIRLS Mean	SD	T value
Spatial relations test	72.37	20.46	68.77	19.40	.34
Match box corners	3.79	4.54	3.21	4.70	.22
Multiple aptitude test	7.89	3.77	7.58	3.55	.15
Shapes & models	3.44	2.67	3.23	2.64	.14

Table 1 Means, Standard Deviations and t test results on the four spatial tests for boys and girls.

Variable	Component Analysis
Spatial factor	.67
Computations	.88
Concepts	.92
Applications	.90
Grades	.43

Table 2 Principal axis loadings for the spatial factor and mathematical performance variables on the total sample

Variable	Component analysis	
Spatial relations test	.47	.30
Match box corners	.43	.29
Multiple aptitude tests	.57	.23
Shapes and models	.66	.28
Computations	.84	.29
Concepts	.88	-.22
Applications	.87	-.26
Grades	.40	-.22

Table 3 Principal axis loadings for the four spatial tests and mathematical performance variables on the total sample

Mathematical variable	Correlation
Computation	.58***
Concepts	.63***
Applications	.61***
Grades	.24***

*** p<.001

Table 4 Correlations of the four mathematical performance measures with the spatial factor variable on the total sample

Variable	Component analysis Boys	Girls
Spatial factor	.67	.69
Computations	.89	.88
Concepts	.89	.94
Applications	.90	.91
Grades	.38	.46

Table 5 Principal axis loadings of the spatial factor and mathematical performance variables for boys and girls

Dependent variable	Independent variable	Standardised coeff.	Improving F	Multiple r	Simple r
Computations	Spatial Factor	.58	175.28***	.575	.58
	Sex	.15	12.30***	.594	.13
Concepts	Spatial Factor	.63	232.31***	.629	.63
	Sex	.12	7.54**	.639	.09
Application	Spatial factor	.62	212.60***	.612	.61
	Sex	.12	8.65**	.624	.10
Grades	Spatial Factor	.25	22.41***	.244	.24
	Sex	.18	12.25***	.301	.17

***p<.001
**p<.01

Table 6 Regression analysis of the four mathematical performance measures using the spatial factor and gender variables

Maths variable	Correlations Boys	Girls	T value
Computations	.56	.61	-.65
Concepts	.63	.64	-.22
Applications	.63	.61	.22
Grades	.20	.30	-.99

Table 7 Differences in correlations of the spatial factor variable with the performance variables for boys and girls.

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