Spatial Visualisation and Cognitive Style: How Do Gender Differences Play Out?

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This study investigated potential gender differences in a sample of 807 Year 6 Singaporean students in relation to two variables: spatial visualisation ability and cognitive style. In contrast to the general trend, overall there were no significant gender differences on spatial visualisation ability. However, gender differences were prevalent among students who possessed high spatial visualisation ability, in favour of boys. In terms of cognitive style, there were significant gender differences in the spatial imagery and verbal information processing dimensions. Boys gave higher ratings to their spatial-imagery encoding and processing preferences than their verbal information processing preferences. Some of these findings are in contrast to studies undertaken in the educational-psychology literature. Implications are drawn regarding pedagogical practices in Singaporean schools.

There has been sustained interest from both mathematics educators and psychologists to understand how spatial ability operates and develops. Due to its strong correlation to performance in mathematics and science (Sinclair & Bruce, 2014), spatial ability continues to attract research attention. Spatial ability is generally regarded in terms of mental rotation, spatial relation, spatial orientation and spatial visualisation, although these concepts are not always used with the same consistency, to some extent because of the complex relationships among them (Carroll, 1993; Clements & Battista, 1992; Höffler, 2010). Relatedly, the inconsistencies in the definition of spatial constructs and their measurement by different standardised spatial tests make the comparison between studies problematic (Voyer, Voyer, & Bryden, 1995). This study focuses particularly on spatial visualisation that involves "the ability to 'see', inspect, and reflect on spatial objects, images, relationships and transformations" (Battista, 2007, p.843). It may involve elements such as holding a visual pattern in memory, comparing visual patterns, or doing a mental transformation and requires the manipulation of internal (mental) representations. Although there has been much interest in understanding how boys and girls operate on spatial visualisation tasks (Voyer et al., 1995), what has not been fully explained, is the significance of cognitive style in the relationship between spatial visualisation and gender, especially at the primary level in mathematics education. This research gap is the rationale for the current study.

Spatial Visualisation and Gender Differences

There is considerable evidence pointing to the fact that boys and girls differ in their spatial abilities (Battista, 1990; Ben-Chaim, Lappan, & Houang, 1988; McGuinness, 1993; Voyer et al., 1995). This tendency is equally observed in terms of spatial visualisation (Mayer & Massa, 2003). Different explanatory factors have been put forward to explain why boys and girls differ in spatial ability, recognising the contribution of both learner-related factors (such as cognitive variables) and environmental factors (such as activities in which boys and girls are engaged in their daily life). In terms of learner-related factors, substantial attention has focused on the ways in which boys and girls encode and process

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information, what is commonly referred to as cognitive style (Arnup, Murrihy, Roodenburg, & McLean, 2013; Kozhevnikov, 2007; Mayer & Massa, 2003).

Cognitive Style and Gender Differences in Mathematics Learning

Blazhenkova & Kozhevnikov (2009) distinguished among three categories of learners, namely object imagers, spatial imagers and verbalisers. Object imagers prefer to use colourful, concrete, high-resolution and pictorial images of objects to interpret information. Spatial imagers prefer to represent schematic images and spatial relations. The third category of people, verbalisers, has a preference to process information verbally. This study is framed within this three-tier categorisation of cognitive style. There is research to suggest that boys and girls differ on cognitive dimensions. For instance, Arnup et al. (2013) observed that boys with an analytic imagery cognitive style had higher mathematics performance compared to corresponding girls. Anderson, Casey, Thompson, Burrage, Pezaris, and Kosslyn (2008) reported that girls with high spatial-imagery cognitive style performed better on geometry tasks, compared to those who had lower spatial-imagery scores. Blazhenkova, Becker, and Kozhevnikov (2011) found that males scored higher on the spatial-imagery dimension while females had higher object-imagery scores, with no gender differences on the verbal information processing dimension.

Condensing the findings from the cognitive style and spatial visualisation literature, the following two patterns emerge: (1) boys tend to fare better than girls in spatial visualisation tasks and (2) boys tend to use more spatial imagery information processing than girls. Building on these findings, we hypothesised that the extent to which students use spatial imagery would be a significant determinant in their spatial visualisation ability. In particular, girls who have high spatial imagery cognitive style would have high spatial visualisation ability.

Examining the relation between spatial imagery as a cognitive style and its relation to spatial visualisation as an ability is premised on the assumption that the latter involves processing requirements shared by the former. A corresponding question is then to what extent do boys and girls process spatial information differently and how are these related to spatial visualisation ability? Thus, we posed and revisited the following two questions:

1. How do boys and girls vary in terms of spatial visualisation ability and cognitive styles?
2. Does gender interact with cognitive style on spatial visualisation ability?

Method

This paper emanates from a larger cross-cultural study (Lowrie, 2013) designed to investigate the ways in which students process mathematical information from two different cultures, Singapore and Australia. The participants (age range 11-12 years) for this paper were the Singapore cohort and included 807 Grade 6 students (392 boys and 415 girls) from 8 Singaporean schools (6 government and 2 government-aided). The schools were chosen from different regions of Singapore on the basis of their willingness to participate in the study. Two instruments were used to collect data in April 2013. Both instruments were administered on the same day by the research team according to the guidelines of the tests (Ekstrom, French, & Harman, 1976; Blazhenkova et al., 2011). Correlations, t-test, and factorial ANOVA were used to analyse the data in line with the two research questions.

Instrument 1: Measurement of Cognitive Style

The Children's Object-Spatial Imagery and Verbal Questionnaire (C-OSIVQ) (Blazhenkova et al., 2011) is premised on three dimensions of cognitive styles: (i) object-imagery, (ii) spatial-imagery, and (iii) verbal information processing. The instrument consists of 15 items from each dimension. Participants rated the 45 items on a 5-point Likert scale (1 = total disagreement; 5 = total agreement). The scores in each of the three sets are averaged to produce an object-score, a spatial-imagery score and a verbal information processing score. A sample item from each of the three dimensions are presented for descriptive purposes: (i) My visual images are like colorful photographs, or pictures of real objects and scenes (object-imagery), (ii) I can easily imagine and rotate three-dimensional figures in my mind (spatial-imagery) and (iii) My verbal abilities would make me a good writer (verbal information processing).

Instrument 2: Measurement of Spatial Visualisation Ability

The Paper Folding Test (PFT) (Ekstrom et al., 1976) is a commonly used instrument for measuring spatial visualisation ability both in Educational Psychology and Mathematics Education. In this timed test, students are required to visualise the folding and unfolding of a square sheet of paper with a punched hole (see Figure 1). The PFT consists of 20 items. A correct item is given a score of 1 mark. Incorrect items are negatively marked. The total score is calculated as follows: Number of items marked correctly minus one-fifth the number marked incorrectly (Mayer & Massa, 2003).

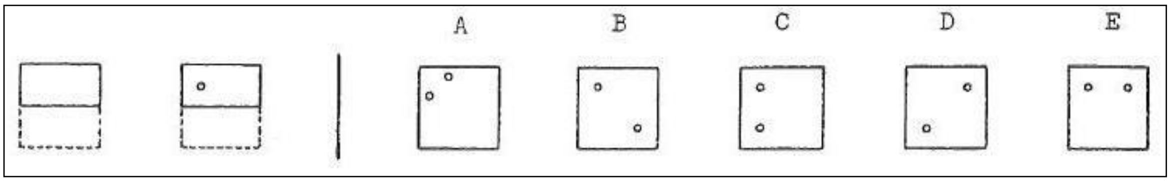


Figure 1. Paper Folding Test[1]

Results and Discussion

Descriptive Statistics

Table 1 presents the mean performance of boys and girls on the two instruments.

Table 1
Distribution Characteristics of the Instruments

Test	Mean		Standard Deviation	
	Boys	Girls	Boys	Girls
PFT	10.14	9.82	4.40	3.95
Object	3.73	3.81	0.68	0.67
Spatial	3.57	2.95	0.71	0.74
Verbal	3.16	3.29	0.67	0.65

[1] *The Paper Folding* Test is reproduced with license and permission of Educational Testing Service, New Jersey, USA.

Boys' scores were higher than that of girls' on the Paper Folding Test. Similarly boys had higher spatial-imagery scores. We comment on the statistical significance of these differences at a later point.

Table 2 shows the correlation between the three dimensions of cognitive style and spatial visualisation, interpreted from a gender perspective. Spatial visualisation, as measured by PFT, was correlated to object imagery for boys and for both boys and girls for the spatial imagery dimension, although the value of the correlation coefficient was larger for boys. There were no significant correlations between verbal information processing and spatial visualisation. It is to be noted that there were correlations among the three dimensions of the C-OSIVQ questionnaire.

Table 2
Correlation Among Variables with Focus on Gender

Measure	Object		Spatial		Verbal		PFT	
	B	G	B	G	B	G	B	G
Object	1	1	.51**	.43**	.54**	.57**	.14**	.02
Spatial			1	1	.34**	.34**	.29**	.16**
Verbal					1	1	.04	.05
PFT							1	1

Note: ** p < 0.01

Research Question 1: How Do Boys and Girls Vary in Terms of Spatial Visualization Ability and Cognitive Styles?

Gender differences on the Paper Folding Test. Overall, there were no gender differences on the Paper Folding Test (Boys: M = 10.14, SD = 4.40; female: M = 9.82, SD = 3.95), t(802) = 1.059, p = 0.290. The students' scores on the PFT were split into three categories to determine whether there were gender differences among students with different levels of spatial visualisation ability. The participants were classified into Low-SV (bottom 25% of the distribution, PFT score <6.8), High-SV (top 25% of the distribution, PFT score >13) and Medium-SV (middle 50%, PFT score between 6.8 and 13). Table 3 shows that gender differences were only significant among those students who had high spatial visualisation ability, with boys faring better than girls.

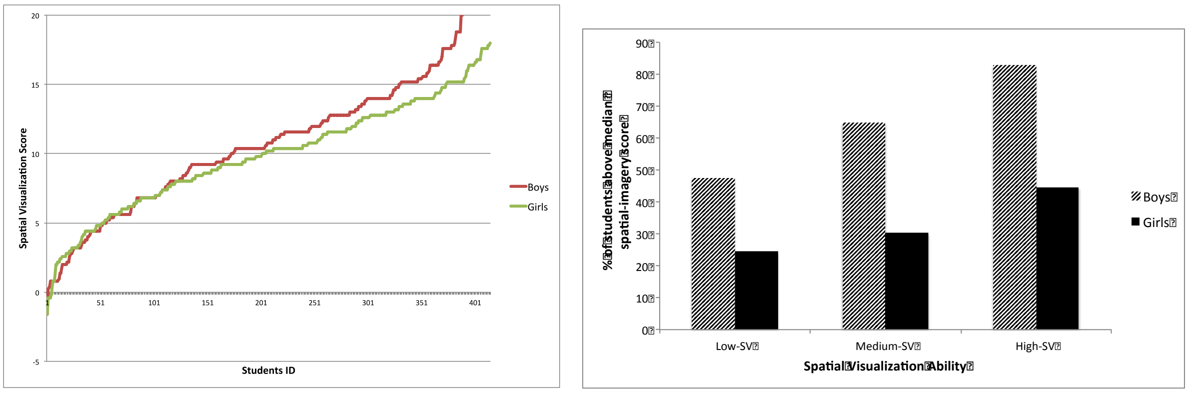
Table 3
Comparison of Boys and Girls Spatial Visualisation Ability from PFT

Level of SV	Number		Mean		t-value	Sig.
	B	G	B	G		
Low-SV	102	101	4.33	4.51	t(201) = -0.666	p = 0.506
Medium-SV	186	224	10.44	10.16	t(408) = 1.708	p = 0.088
High-SV	101	90	15.46	14.98	t(189) = 2.216	p = 0.028

The spatial visualisation scores for boys and girls were sorted separately in ascending order and plotted in Figure 2(a). Noteworthy, the gap between genders in spatial visualisation ability begins to appear as the score on the PFT crosses 10 points.

Gender differences on the C-OSIVQ questionnaire. In terms of cognitive styles, there were significant gender differences between the spatial imagery ($t(741) = 11.555$, $p = 0.000$) and verbal information processing dimensions ($t(758) = -2.500$, $p = 0.013$). For spatial imagery, the male scores were higher; for verbal processing, female scores were higher (see Table 1). Further, boys gave higher ratings to their spatial-imagery encoding and processing preferences than their verbal information processing preferences. The opposite tendency was observed for girls. No significant gender differences were observed for the object imagery dimension ($t(754) = -1.543$, $p = 0.123$). In their study, Blazhenkova et al. (2011) noted a similar pattern for the spatial imagery dimension, however they did not find differences in verbal information processing but rather on the object dimension, in favour of girls.

In Table 2, we observed that there were significant correlations between spatial-imagery and PFT for both boys and girls. Figure 2(b) shows in further detail how the level of spatial visualisation ability is related to spatial-imagery differentially for boys and girls. In Figure 2(b), the vertical axis represents the percentage of boys and girls whose scores on the spatial-imagery scale were higher than the group median. Thus, this category of students would be regarded as having a preference for spatial imagery. Across all three levels of spatial visualisation ability, there were almost twice as many boys as girls who had spatial imagery scores above the median. Further, the percentage of boys and girls who preferred to use spatial imagery were higher in the high spatial visualisation (High-SV) group than in the low spatial visualisation (Low-SV) group. This gives further evidence that there is a relationship between spatial visualisation ability and spatial imagery as a cognitive style.



(a) (b)

Figure 2. Differences between boys' and girls' scores on (a) PFT, and (b) spatial-imagery scores

Research Question 2: Does Gender Interact with Cognitive Style on Spatial Visualisation Ability?

Students were grouped in 8 categories, depending on whether they were below or above the medians in each of the three dimensions of the cognitive style (2 object x 2 spatial x 2 verbal). We coded the scores below the median as 1 and above the median as 2. For example, a student who scored low on the object-imagery, spatial-imagery and verbal information processing respectively, was coded as 111 while a student whose scores were above the median in all the three categories was coded as 222. This categorisation partitioned the sample into 8 classifications of students as shown in Table 4. The majority of boys and girls were either in the category 111 or 222. Boys who had high spatial visualization ability were primarily from group 222 (high object imagery, high spatial imagery and high verbal information processing) and similar girls were from 111 or 222.

Table 4
Distribution of Students by Cognitive Style

Cognitive Style	111	112	121	122	211	212	221	222
Boys (%)	20.1	6.6	17.4	7.5	4.2	3.3	12.9	27.9
Girls (%)	30.2	9.8	3.3	5.2	9.3	19.1	5.7	17.4
Total (students)	178	58	70	44	48	81	64	156
High-SV Boys (%)	13.8	2.3	21.8	8.0	1.1	1.1	16.1	35.6
High-SV Girls (%)	25.9	11.1	7.4	2.5	4.9	14.8	9.9	23.5

A factorial ANOVA was carried out with spatial visualisation as dependent variable and cognitive style and gender as independent variables. There was a significant main effect of cognitive style $F(7, 683) = 6.110$, $p < 0.000$, $\omega^2 = 0.05$), indicating that it influenced the participants' score on the spatial visualisation test. The non-significant effect for gender ($F(1, 683) = 2.564$, $p < 0.110$) showed that it did not influence the spatial visualisation scores, other things being equal. However, the significant interaction effect between gender and cognitive style ($F(7, 683) = 2.142$, $p < 0.037$, $\omega^2 = 0.01$) demonstrated that the influence of cognitive style on spatial visualisation was different for male participants than it was for females. Figure 3 shows the variations in cognitive style against performance in PFT.

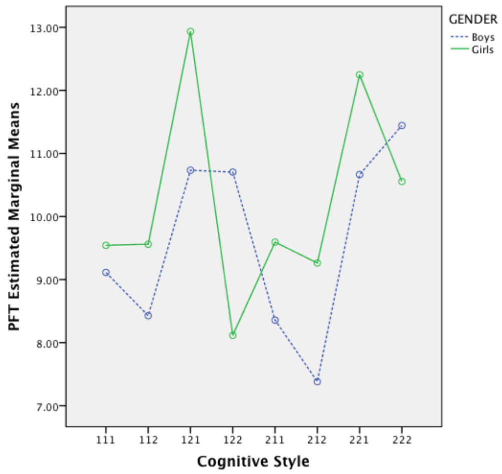


Figure 3. Variation in cognitive style and spatial visualization score

Conclusion

We make two conclusions in terms of gender differences in spatial visualisation ability, cognitive style and their interactions. Firstly, in contrast to research findings (e.g., Battista, 1990), there were no gender differences overall in spatial visualisation ability for this cohort of Singaporean students. The only significant differences were among students with high spatial visualisation ability, in favour of boys. One possible explanation for the absence of gender differences overall for the Singaporean students (as compared to the general trend), is that visualisation is explicitly emphasised in the Singaporean curriculum (Ministry of Education Singapore, 2012). Thus, the nature of the mathematics curriculum may be an influential factor in explaining gender differences related to spatial ability.

Secondly, in terms of cognitive style, boys gave higher ratings to their spatial imagery information processing mode in contrast to girls. Further, as the level of spatial visualisation increased from low, medium to high, the percentage of boys and girls who used spatial imagery increased. This consolidates the finding that spatial imagery information processing is related to spatial visualisation. Correlations between spatial visualisation and spatial imagery were higher for boys than for girls. The significant interaction between gender and cognitive style suggests that spatial-imagery may be operating differently for boys and girls. Although the present findings do not provide strong evidence for a direct relationship between spatial imagery and spatial visualisation ability, the results do suggests that cognitive style is an influential factor in manipulating mental images as is characteristic of spatial visualisation. It is acknowledged that there are other factors besides cognitive style that explains why boys and girls performed differently on spatial visualisation tasks.

The results of this study are dependent on the operational definition of constructs and instruments that were used to measure spatial visualisation and cognitive style. We focused on cognitive style from the object-spatial-verbal dimension while we measured spatial visualisation from only one instrument, i.e., the PFT. As we make further attempts to understand the ways in which cognitive style plays out in spatial visualisation, it is important to use different instruments and consider diverse conceptual underpinnings to unfold the link between unobservable constructs as in processing mathematical information and spatial skills. For instance, it may be insightful to qualitatively follow boys' and girls' responses to the spatial visualisation tasks in the PFT in future interview-based investigations.

The current study contributes in expanding the knowledge base on gender differences on spatial reasoning based on a relatively large sample of students. It revisits an issue that requires the attention of educators. Methodologically, it highlights the necessity to perform analysis by level of students to understand the underlying structure or to reveal patterns that may not be visible otherwise.

As we design curricular experiences to develop spatial skills in school mathematics, it is important to understand general trends in which boys and girls may differ in processing spatial information. Due to its methodological approach the current study may not provide direct instructional guidelines but the disparities in spatial visualisation ability and spatial imagery cognitive style between boys and girls do suggest that there is a necessity to support girls more explicitly so that they develop a spatial habit of mind, an aspect that may not be explicitly fostered socially and educationally.

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