Students' Ability to Solve Mental Rotation Items: Gender Perspective Within a Disadvantaged Community

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Studies about gender difference in mental rotation ability are well documented in the context of developed countries; though not in developing or low-income ones. This paper examined students' mental rotation ability as a function of gender in a disadvantaged community in Indonesia. The Spatial Reasoning Instrument (SRI) was used to test 334 students (aged 13-14 years old) in an untimed test. The characteristics of the SRI items were analysed in relation to the gender difference. The results showed a significant difference in favour of males on both 2D and 3D mental rotation tasks. The effect of the task direction was mediated by gender; girls performed significantly lower than boys for the task with an implicit direction.

Mental rotation refers to a cognitive process in which a person imagines how two-dimensional (2D) and three-dimensional (3D) objects would appear after being turned around a point by a certain angle (Shepard & Metzler, 1971). Tests of mental rotation commonly involve a comparison of 2D or 3D figures to determine whether they are a rotation of the same objects (Bodner & Guay, 1997; Cooper, 1975; Shepard & Metzler, 1992; Vandenberg & Kuse, 1978). Recently, mental rotation tests have included drawings of animals, alphanumeric symbols and other images (Jansen, Schmelter, Quaiser-Pohl, Neuburger, & Heil, 2013; Ramful, Lowrie, & Logan, 2017).

Studies in the field of mental rotation ability show evidence for gender differences (Moè, 2016; Titze, Jansen, & Heil, 2010) in which boys tend to perform better than girls on mental rotation tasks, with variability in the magnitude of reported differences. The majority of these studies were conducted in developed countries (Linn & Petersen, 1985; Maeda & Yoon, 2013; Voyer, Voyer, & Bryden, 1995), rarely in developing countries. While less than 20% of countries in the world are classified as "developed" countries (United Nations, 2019), these countries make up the vast proportion of research populations. More studies are needed in developing countries since women remain underrepresented in Science, Technology, Engineering and Mathematics (STEM) fields, particularly in developing countries like Indonesia (Baskaran, 2017). Knowing the role gender differences have in mental rotation ability within the context of developing countries may provide a focus for teachers in supporting education in STEM fields in these countries.

Factors Influencing Gender Difference in Mental Rotation

There has been sustained research investigating the cause of gender difference in mental rotation. The factors can generally be classified into biological (by nature) and social (by nurture) factors. In the 1970s, several researchers reported that biological factors influenced the gender difference in spatial ability (e.g., Buffery & Gray, 1972; Harris, 1978; Waber, 1977). In subsequent decades, some studies questioned the previous findings, while some others confirmed it. Kurth, Spencer, Hines, and Luders (2018) found that the size of the corpus callosum affected mental rotation ability for females – but not for males. On the other hand, King, Katz, Thompson, and Macnamara (2019) reported that spatial ability was largely heritable for males and females. To date, there is no certain conclusion to what extent biological factors influence spatial ability including mental rotation ability.

Research has given much attention to the social (nurture) factors influencing gender differences in mental rotation. Test characteristics, such as time limit and scoring criterion

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have been found to affect gender differences in mental rotation tasks (Goldstein, Haldane, & Mitchell, 1990). In the timed test, boys yielded higher performance than girls but not in the untimed test. When raw scores were used (i.e., by counting the correct answers), boys performed significantly better than girls, but when the ratio-score criterion (ratio of correct answers and the number of items attempted) was applied, there was no male advantage. This suggests that although in a given time period females may not complete as many items, their error rates were lower.

Item difficulty is another factor in gender differences according to Collins and Kimura (1997). They found that when the task difficulty in the 2D mental rotation task was varied, the males were advantaged. Heil and Jansen (2008) investigated a function of stimulus complexity (i.e., using polygons) in mental rotation. Their finding showed that the more complex the polygon (i.e., more sides), the longer the time was required to mentally rotate and consequently increased the gender difference. This study also concluded that women were mentally rotating the polygon in an analytic, fragmented way; while men used a holistic mode of mental rotation. The consideration of ensuring appropriate stimuli in mental rotation tasks was proposed by Jansen et al. (2013). They found that a mental rotation task with cube figures was too difficult for children in Year 2 and 4, while the use of animal drawings and letters showed a significant gender difference in reaction time favouring boys.

The characteristic of item/stimulus has been investigated to be one of the social factors that influence mental rotation ability. Heil and Jansen (2008) explained that males rotated faster than females for items when presented with more complex polygons, which increased the gender difference. Similarly, in a recent study by Fisher, Meredith, and Gray (2018) a significant difference was found when the stimuli were in isometric form, but there was no gender difference when the stimuli were presented in the form of a photograph or 3D mounted on boards (Fisher et al., 2018). Another study by Bilge and Taylor (2017) found that men rotated more accurately than women but the sex difference was not robust and the speed of rotation was influenced by the entirety of the object (whole faster than segment) and the presence of a frame of reference. The variability in factors affecting gender difference in mental rotation is an important area of study in the middle school where mental rotation tasks are embedded within a curriculum context (Ramful et al., 2017).

The Goal of This Study

This study investigated the mental rotation ability of students aged 13 to 14 years old from a disadvantaged community in a developing country (i.e., Indonesia), which has a different context from most previous studies on mental rotation ability. Gender difference in mental rotation ability was explored through an analysis of performance on a spatial reasoning test.

Method

This study is a part of an ongoing PhD project investigating the impact of a spatial intervention program on students' mathematics performance. This paper, however, will report on mental rotation performance of students and the influence of gender. The participants were selected from students aged 13 and 14 years old (mean = 13.63, SD = 0.49). There were 334 students (173 boys and 161 girls) from 10 schools in West Nusa Tenggara, Indonesia involved in this study. According to the Indonesian census in 2010, West Nusa Tenggara is in the 5th lowest human development index (HDI) of 34 provinces in Indonesia where the living standard in this area including education, health and economics is below the average standard of living in Indonesia. Therefore, West Nusa Tenggara is one of the most disadvantaged areas in Indonesia.

Spatial Reasoning Instrument-Mental Rotation (SRI-MR)

The Spatial Reasoning Instrument-Mental Rotation (SRI-MR) is a subtest of the SRI to measure the spatial ability of students in middle school level (11-13 years old) developed by Ramful et al. (2017). Overall, the SRI consists of 30 items, evenly distributed into 10 spatial visualisation items, 10 mental rotation items and 10 spatial orientation items. The SRI-MR is a combination of different types of items similar to previous mental rotation tasks (Cooper, 1975; Quaiser-Pohl, 2003; Shepard & Metzler, 1971; Vandenberg & Kuse, 1978) but contextualised with curriculum-style questions (Ramful et al., 2017). The SRI-MR items include both 2D and 3D mental rotation tasks with graphic features such as cube blocks, animals, polygons and other miscellaneous drawings. The task directions include both *explicit* direction where it is clearly stated in the task to rotate the shape (with or without any course of direction and/or degree of rotation) and *implicit* direction where the task does not include the rotation direction. Instead, the task includes a direction to look for an equal shape or position.

The SRI instrument was chosen for this study because of its setting within a school context. Participants in this study completed the whole SRI, but only the results of the mental rotation items are reported here. The SRI was translated into Bahasa Indonesia without changing the content of the instrument. The translated instrument was then validated by educator experts in Indonesia and was trialled by students who were not included in this study. The reliability of the SRI was measured, and the value of Cronbach's Alpha was 0.71, which showed the acceptable internal consistency.

The paper-pencil SRI was administered in 10 different schools on the same day and time. A classroom teacher, with the assistance of one research assistant, administered the test in their respective classes. A week prior to the test date, the parents/guardians received notification from school, and those willing to participate signed the consent declaring that they allowed their children to participate in the study.

Data Analysis

Each SRI-MR item with the correct answer was scored 1, and a wrong answer or no answer was scored 0 with the total score of 10 for all correct answers. The items were classified into several characteristics (see Table 1) and used as a grouped variable in the quantitative data analysis in SPSS. The items were classified into: (1) tasks with 2D figures coded as 2D or 3D figures code as 3D; and (2) tasks with an explicit direction coded as E or implicit direction coded as I. Tasks with an explicit direction were further categorised into an explicit rotation direction with the course of direction and degrees of rotation, coded as E1, an explicit direction with the course of direction but without any degree of rotation, coded as E2, and an explicit direction without any course of direction and degree of rotation, coded as E3. Examples of SRI-MR items for each classification are provided in the Appendix.

Table 1
Classification of items based on the level of difficulties, dimensionality and direction given

Items	1	2	3	4	5	6	7	8	9	10
Level of difficulties	1	6	3	9	7	5	10	8	2	4
Dimensionality	2D	2D	2D	2D	3D	2D	2D	3D	3D	2D
Task direction	E1	E3	E2	E3	I	E1	I	I	E3	E1

Note - Level of difficulties: 1 is the easiest and 10 is the hardest (based on the number of students who give correct answer).

An ANOVA analysis was conducted to determine the differences in mental rotation ability across gender. In addition, gender difference was also assessed with a MANOVA analysis based on the characteristics of the items.

Results

Results from this study are presented in two parts, according to the aims of this study. Part 1 presents the results of students' overall mental rotation scores and across gender. Part 2 reports the gender difference in mental rotation score based on the item characteristics.

Mental Rotation Ability Overall and Across Gender

An ANOVA analysis was conducted to determine the gender difference in terms of mental rotation ability. The results showed a significant difference between boys and girls in mental rotation ability, in favour of boys, $F(1{,}332) = 20.67, p < 0.001, \eta^2 = 0.06$. Table 2 shows the overall mean and standard deviation (SD) of participants and across gender on their mental rotation test.

Table 2
Mean and standard deviation of mental rotation test score

Gender	Mean	SD
All participants	3.62	2.04
Girls (161)	3.11	1.66
Boys (173)	4.10	2.24

The results in this study confirmed the previous finding that gender difference favouring boys still exists in mental rotation ability with a medium effect size ($\eta^2 = 0.06$). Another interesting result is that gender difference favouring boys was still present in an untimed test.

Mental Rotation Ability Across Gender Within SRI-MR Items Classification

The SRI-MR items used in this study were classified based on the dimensionality of the figure used in the task and the direction given in each task (see Appendix). Students' mental rotation scores were analysed across gender for each of the item classifications.

Mental rotation ability across gender based on the dimensionality of the items.
The mental rotation items were classified into 2D and 3D items. A MANOVA analysis was conducted to see the gender difference on mental rotation ability between those items' classifications. The result of the analysis showed that the variance of scores in 3D items violated the assumption of homogeneity. Therefore, the 2D scores were analysed with an ANOVA, and 3D scores were analysed with an ANOVA, Welch test (Pallant, 2013). ANOVA analysis showed that there was a significant difference between gender favouring boys in 2D mental rotation scores, $F(1{,}332) = 17.07, p < 0.001, \eta^2 = 0.05$. Meanwhile, the ANOVA, Welch test result showed a significant difference in 3D mental rotation scores favouring boys, $F(1{,}317.41) = 8.13, p = 0.005, est\ \omega^2 = 0.02$. Table 3 shows the mean and standard deviation (SD) across gender on their mental rotation test within dimensionality item classifications.

Table 3
Mean and standard deviation of mental rotation score within dimensionality classifications across gender

Items Classification	Boys		Girl	
	Mean	SD	Mean	SD
2D (7 items)	2.97	1.62	2.26	1.49
3D (3 items)	1.13	1.03	0.85	0.77

Mental rotation ability across gender based on the task direction given.

The mental rotation items were classified into items with implicit direction (I) and items with explicit direction (E). The explicit direction items were further classified into E1, E2 and E3 (see table 1). The MANOVA analysis was conducted, and the results showed that for all types of direction there was a significant difference among genders, in favour of males. The largest effect size was found for implicit direction items (see Table 4)

Table 4
The MANOVA result of mental rotation scores among gender based on the direction given

Item classification	df	F	Sig (P)	Partial Eta Squared
E1 (3 items)	1	5.06	0.03*	0.02
E2 (1 items)	1	8.24	0.00*	0.02
E3 (3 items)	1	5.22	0.02*	0.02
I (3 items)	1	20.27	0.00*	0.06

* Significant at the 5% level

Discussion and Conclusion

This study, in general, showed that the average score in a mental rotation test for boys and girls was low. Of the total score 10 (all correct) the average score was only 4.10 for boys and 3.11 for girls (see Table 1). The context of education in Indonesia might be able to explain this result. Mental rotation or spatial ability are seldom mentioned in the Indonesian curriculum. Even though there is a unit chapter about rotation, it is not, in particular, exploring mental rotation. According to the information gathered by the author during the data collection, classroom teachers and students were generally unfamiliar with the concepts of mental rotation and spatial ability more generally. Therefore, mental rotation tasks are likely to be very novel to them. What is noteworthy is that for explicit direction tasks (i.e., that contain some mathematical reference, such as degrees or course of direction) a smaller effect was found than the implicit direction tasks (i.e., those requiring pure mental rotation ability). This suggests that the small exposure to rotation in the curriculum may have ameliorated gender difference somewhat for explicit tasks. Research has shown that spatial ability is malleable (Uttal et al., 2013), therefore giving these students 2nd or 3rd attempts might help them to perform better.

This study also confirmed a consistent finding in mental rotation studies where boys performed better than the girls in mental rotation tasks (Moè, 2016; Titze et al., 2010). Noteworthy, most of these studies were conducted in contexts of relative advantage within Western societies. One factor associated with these differences is the timed-natured as these tests. The current study was untimed, yet a significant gender difference was revealed (with a medium effect size was obtained). Other researchers, for example, Levine, Vasilyeva, Lourenco, Newcombe, and Huttenlocher (2005), found no gender difference for low SES-groups in advantaged communities. It is important to note that the context of disadvantaged areas in developing countries could be very different from the context of low SES-groups in developed countries and therefore future work should continue to explore spatial abilities in developing countries given its value in supporting STEM education and careers (Wai et al., 2009).

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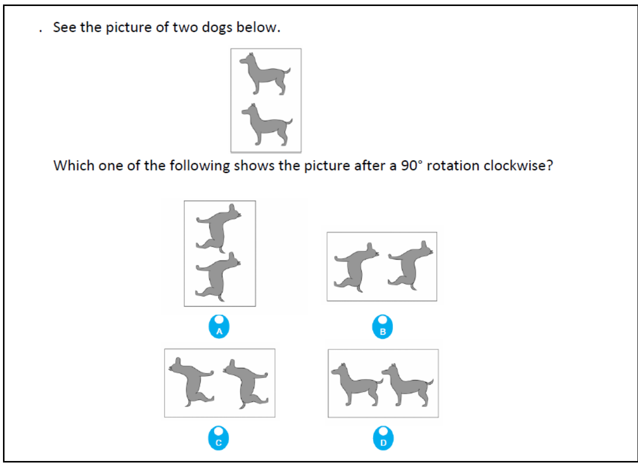
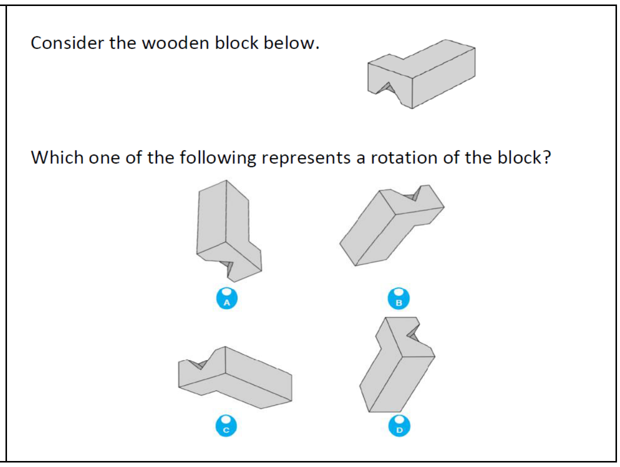
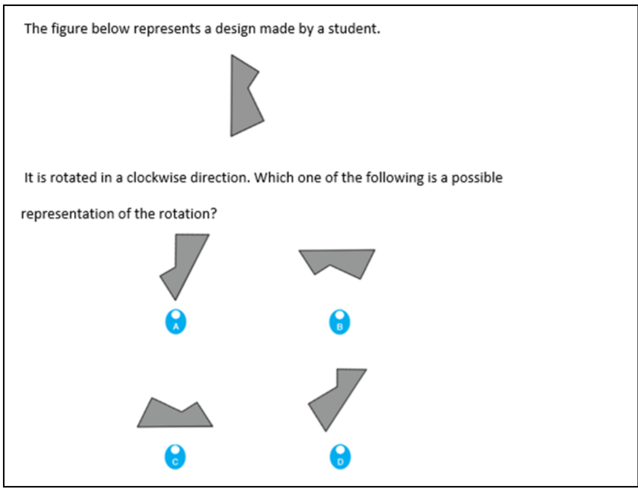
Appendix: Examples of SRI-MR items



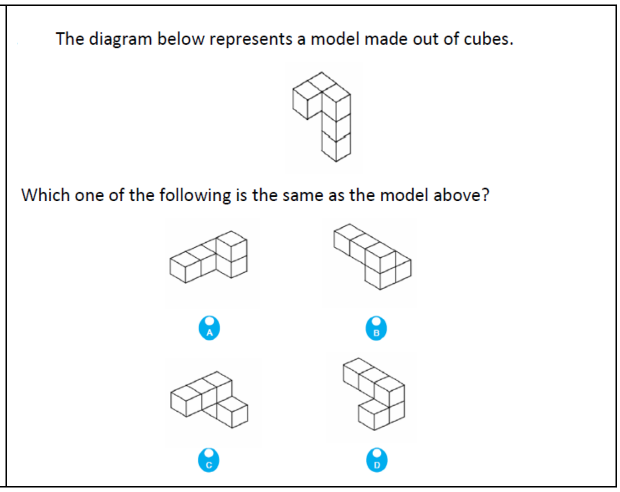
Item test with 2D figure (E1)



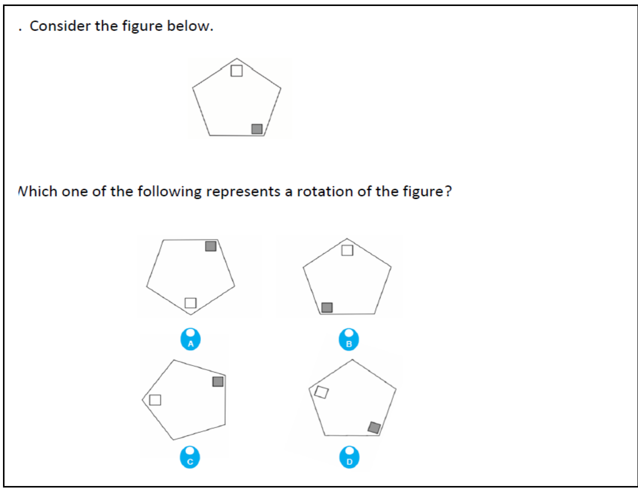
Item test with 3D figure (E3)



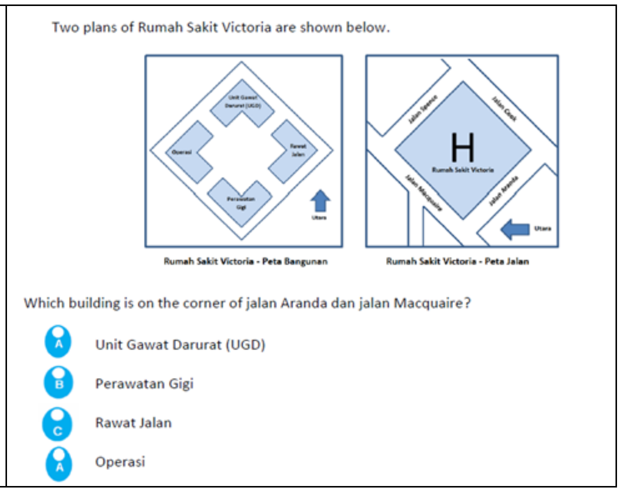
Item test with 2D figure (E2)



Item test with 3D figure (I)



Item test with 2D figure (E3)



Item test with 2D figure (I)