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Students' Performance on Graphics-rich Mathematics Tasks: Interactions between Gender and Culture

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Abstract: This study compared the performance of Singaporean (N = 607) and Australian (N = 580) students who completed six graphics-rich mathematics tasks sourced from Australia's national numeracy assessment program. Although Singaporean students typically perform better than Australian students on mathematics tests, these graphics tasks would be considered novel for the Singaporean students. The research design examined cross-country and gender differences among these two cohorts of students. The results of the study revealed significant performance differences in the favour of (1) the Singaporean students; and (2) males on these graphics items. In addition, interaction effects were revealed in relation to gender and country on graphics tasks that required visual recognition and the rotation or orientation of objects. Findings include recognition that out-of-school learning maybe influential in student performance.

Keywords: spatial reasoning; graphics tasks; mathematics assessment; gender; cross-country comparisons.

Introduction

In recent years there has been increased attention in how school students solve graphics tasks. Such tasks are becoming increasingly used to assess students' mathematics competence (see Lowrie & Diezmann, 2009) and have become more prominent in how mathematics is represented. To some degree, the focus on graphics-rich tasks has evolved from advances in technology, with mathematics assessment reflecting applications of mathematics concepts. In countries such as Singapore and Australia, graphics-based tasks have replaced more traditional word problems in national assessments. However, the focus on graphics-based tasks is not consistent across these countries. For example, Australia's National Assessment Program: Literacy and Numeracy (NAPLAN) consists of

approximately 70% of graphics tasks, whereas Singapore's Primary School Leaving Examination (PSLE) constitutes 41% of items that are graphics based (Lowrie, 2012). The Singaporean graphics items tend to reflect geometry and measurement concepts that contain diagrams or information presented in tables. By contrast, the Australian graphics items contain more spatial features and require decoding of information associated with rotations, translations and location and arrangement. This study investigates Singaporean and Australian students' performance on Australian-based graphics tasks, which would be less familiar for the Singaporean students. The study also examines gender since there is a consistent literature base that identifies differences in performance across graphics-rich tasks (Else-Quest, Hyde, & Linn, 2010)

Background

Cross-cultural comparisons of mathematics performance

To date, most studies that compare students' mathematics performance across countries (e.g., Trends in International Mathematics and Science Study [TIMSS]) are derived from mathematics items that have been produced in a hybrid form to reduce cultural bias. Singapore tends to perform extraordinarily well on international assessment indicators, such as the TIMSS and, more recently, the Programme for International Student Assessment (PISA). By contrast, Australia's performance on international assessments is consistently much lower than that of Singapore. The TIMSS assessment focuses on the mathematics knowledge typically addressed in the curriculum, while the PISA assessment measures mathematics literacy associated with the application of mathematics concepts (Else-Quest et al., 2010). The graphics tasks in this investigation would be more closely aligned to PISA questions since the NAPLAN measures students' numeracy. According to the Australian Curriculum, numeracy is seen as a general capability and "involves students in recognising and understanding the role of mathematics in the world and having the dispositions and capacities to use mathematical knowledge and skills purposefully" (Australian Curriculum, n.d.).

Since it is the case that within-country assessment items are culturally based (see Cooper & Dunne, 2000), and typically reflect the teaching practices and

curricula of that country, this study was designed to consider the influence contextual nuances have on students' ability to apply mathematics concepts. Elsewhere, it has been argued that the contextual aspects of mathematics tasks involve much more than the literacy demands, with graphic features especially influential (Diezmann & Lowrie, 2009). In fact, significant effects of students' performance and sense making can eventuate with even the subtlest of changes in how graphics are represented in mathematics tasks (Lowrie, Diezmann, & Logan, 2012). It is certainly the case that Singaporean classrooms have strong cultural teaching practices aligned to Confucian paradigms (Leung, 2001) and explicit teaching of problem-solving heuristics (Ho & Lowrie, 2014). At the same time, students from Singapore continue to perform very well on international studies, such as TIMSS (Kaur, 2003), despite recent criticism that the education system's instructional practices constrain opportunities for students to think flexibly (Hogan et al., 2013). This cross-cultural comparison examined student performance on graphics-rich mathematics tasks from Australia as a way of comparing performance on culturally based tasks.

Gender differences on mathematics tasks

International comparative studies, such as TIMSS and PISA, have highlighted international variation among school students' performance on mathematics tasks. These comparative studies have also revealed distinct performance differences between males and females within and between countries. As Penner and CadwalladerOlsker (2012) pointed out, international variation provides the opportunity to "examine what characteristics of countries are related to larger and smaller gender differences in mathematics achievement" (p. 442) as a way of highlighting plausible factors that may contribute to performance differences.

Miller and Halpern (2014) conducted a meta-analysis of more than 30 years of studies on performance differences between males and females to examine gender differences across cognitive constructs. They found that although performance differences are widely acknowledged, the extent of these differences, the age when these differences occur (and/or diminish), and the nature of the tasks have raised considerable debate. Although some studies have demonstrated that gender differences have diminished in recent years (e.g., Spelke, 2005), other investigations have demonstrated consistent patterns in favour of males (e.g., Thomson, De Bortoli, Nicholas, Hillman,

& Buckley, 2010) or females (e.g., Dindyal, 2008). Within the mathematics domain, males commonly outperform females on tasks that require the mental rotation of objects (Miller & Halpern, 2014) or tasks that require high levels of spatial reasoning (Spelke, 2005).

According to Miller and Halpern (2014), research has been conducted for many years across different domains with the aim to understand why gender differences occur. They suggest that there are a number of factors influencing these gender differences, such as gender stereotypes, culture and the development of the brain. Although exact causes could be a mix of many influences, their research does suggest that "individuals' relative cognitive strengths are important to educational and career decisions" (p. 42), alongside other non-cognitive factors. Hence, while the evidence to confirm that gender differences genuinely exist is debatable, it is still imperative to consider these differences in research with children in order to inform teachers and schools about ways to maximise both gender's cognitive potential.

Design and Methods

The broad aim of the study was to analyse how students from two different cultures solved and processed graphics-rich mathematics tasks from items drawn from one of the respective country's national assessment instruments (Australia). Specifically, the study aimed to determine whether there were any interaction effects between cross-country student performance and gender, since all of the graphics-rich tasks required spatial reasoning.

The following two research questions were posed:

1. Are there differences in Singaporean and Australian students' performance across Australian-developed graphics tasks?
2. Is gender an influential factor in student performance on Australian-developed graphics tasks?

Participants

The participants (N = 1187) comprised 607 Primary 6 students from five Singaporean schools (three government and two government-aided) and 580 Year 6 students from 12 Australian non-government schools. Students were aged 11-12 years and there were 600 males and 587 females.

The instrument and administration

The participants in the study undertook a mathematics sense making test—a 24-item instrument used to determine students' performance across mathematics tasks. It consisted of six graphic and six non-graphic tasks from the NAPLAN, and six graphic and six non-graphic tasks from the PSLE. A graphics task is an item that has a graphic (e.g., picture, diagram, table, chart, graph or map) embedded within the task, where the graphic contains information essential for task solution. A non-graphic task is an item where there is only text (similar to a traditional word problem). This paper focuses on the participants' performance on the six Australian NAPLAN graphics tasks.

Two members of the research team attended the participating schools in both Singapore and Australia during their morning classes. The test was administered to whole (intact) classes to minimise disruption to both the school and the students' daily classroom routine. The classroom teachers and the research staff administered the activity.

Data coding

The participants were scored according to the number of tasks they answered correctly. Hence, the highest possible score was 6 and the lowest possible score was 0.

Results and Discussion

The two research questions were investigated through a Factorial Analysis of Variance (ANOVA) design. The 2(country) x 2(gender) x 6(graphics tasks) ANOVA was conducted to determine whether there were statistically significant differences between student performance. The Factorial ANOVA revealed statistically significant differences between the mean scores of both country [$F(6,1178) = 47.41$, $p < .001$, partial $\eta^2 = .20$] and gender

[$F(6,1178) = 8.83$, $p < .001$, partial $\eta^2 = .04$] variables. There was also a statistically significant interaction effect (country x gender) [$F(6,1178) = 3.47$, $p = .002$, partial $\eta^2 = .02$]. Table 1 presents the means and standard deviations for country and gender for the six graphics tasks.

Table 1
Mean Scores (Standard Deviations) of Singaporean and Australian Males and Females on the Six Graphics Items

Graphics Item	Singapore			Australia		
	Total	Male	Female	Total	Male	Female
Balance	.87 (.33)	.91 (.29)	.84 (.37)	.75 (.43)	.76 (.42)	.74 (.44)
Paper Folding	.58 (.49)	.55 (.50)	.61 (.49)	.41 (.49)	.41 (.49)	.41 (.49)
Spinner	.66 (.47)	.73 (.44)	.59 (.49)	.95 (.21)	.96 (.19)	.94 (.23)
Boxes	.68 (.47)	.71 (.45)	.67 (.48)	.64 (.48)	.65 (.47)	.62 (.49)
Map	.40 (.49)	.42 (.49)	.37 (.48)	.41 (.49)	.50 (.50)	.32 (.47)
Trees	.58 (.49)	.64 (.48)	.52 (.50)	.49 (.50)	.59 (.49)	.40 (.49)

Subsequent univariate analysis was conducted on the country and gender variables in order to determine which items within the respective categories had statistically significant differences. The Bonferroni correction method (alpha levels were adjusted to $p = .008$) was used to avoid Type II error. There were differences on four of the items in relation to the country variable. For three of the items, statistically significant differences were in favour of Singaporean students, namely: the Balance Item [$F(1,1187) = 29.1$, $p < .001$]; Paper Folding Item [$F(1,1187) = 27.12$, $p < .001$]; and Trees Item [$F(1,1187) = 9.70$, $p = .002$]. Australian students outperformed Singaporean students on the Spinner Item [$F(1,1187) = 191.7$, $p < .001$]. Three of the graphics items revealed statistically significant differences in favour of males, namely: the Spinner Item [$F(1,1187) = 16.03$, $p < .001$]; Map Item [$F(1,1187) = 15.44$, $p < .001$]; and Trees Item [$F(1,1187) = 28.33$, $p < .001$].

With respect to differences between the country variable, we could have anticipated that the Singaporean students would perform higher than the Australian students given long-standing performance differences between these countries on international tests (e.g., PISA and TIMSS). What was unexpected, however, was the substantial difference between scores on the Spinner Item, in favour of the Australian cohort. A close inspection of the Singaporean mathematics curriculum highlighted the fact that probability concepts are not addressed in primary school. This lack of explicit concept exposure may have influenced this result. Nevertheless, the graphic information embedded in the task provided sufficient information for students to complete the task successfully without a deep understanding of chance. Thus, it is possible to solve the task provided students can decode the graphic.

Males outperformed females on three of the six graphics tasks. Given these tasks required students to decode visual and spatial information it may well be the case that general visuospatial capacity may have been a determining factor in success. Despite the continued debate around gender differences, a consistently robust finding has been that males tend to perform better than females on spatial tasks (Tzuriel & Egozi, 2010).

There were statistically significant interaction effects for the Spinner Item [$F(1,1187) = 9.10$, $p < .01$] and Map Item [$F(1,1187) = 5.32$, $p < .02$] (Figures 1 & 2).

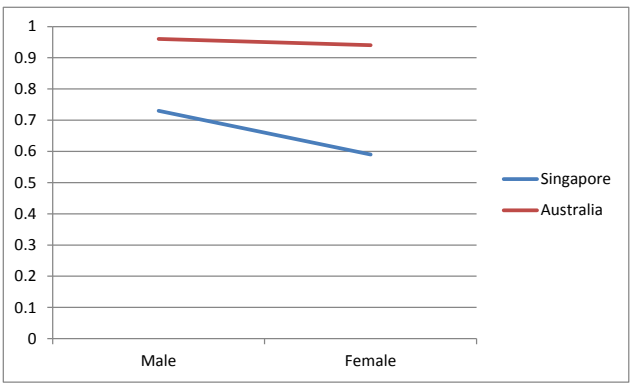


Figure 1. Interaction effect for the Spinner Item.

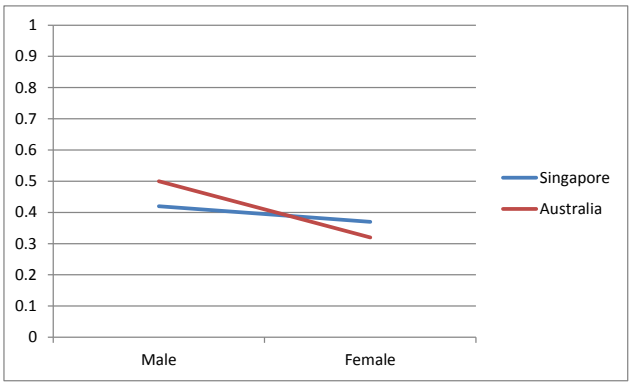
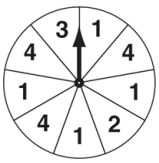


Figure 2. Interaction effect for the Map Item.

With respect to the Spinner Item, Singaporean females, in particular, performed poorly. Noteworthy, the scores of the Australian females were substantially higher than that of the Singaporean males. This interaction effect could be a combination of the Singaporean females' lack of exposure to such probability tasks in out-of-school contexts (Else-Quest et al., 2010) and challenges with visual recognition. For example, Bull, Cleland and Mitchell (2013) suggested that spatial numerical associations may be processed differently by males and females. A majority of the females' incorrect solutions involved the selection of the second most common occurring number, which is the numeral "4" (rather than the most common occurrence "1") (see Figure 3). Noteworthy, two of the numeral 4's are located in positions that draw attention—that is, at approximately 10 o'clock and 2 o'clock on the graphic chart. It may be the case that this visual recognition error is due to the fact that females tend to perform significantly lower than males on *memory for location* tasks (Lowe, Mayfield, & Reynolds, 2003). These tasks require the recall of the location of patterns or objects. Further research needs to be undertaken as to why the Australian female students did not encounter such challenges with the visual recognition of objects.

The spinner is used in a board game.



Sanjay spins the arrow.

On which number is the arrow **most** likely to stop?

Figure 3. The Spinner Item (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2010a, © Australian Curriculum, Assessment and Reporting Authority, 2010).

For the Map Item (see Figure 4), the interaction effect emerged as a result of the high scores from the Australian males and the low scores from the Australian females. This was the most difficult task in the study, presumably because it required the disruption of prototypical thinking. The most challenging aspect of this task involves the re-orientation of the commonly constructed prototype where the "North" direction is always represented at the top of the page. According to Aspinwall, Shaw and Presmeg (1997), the prototypical images we produce in the mind's eye tend to override images we are trying to encode in problem-solving situations. Without relatively sophisticated levels of visualisation, it is difficult to reconstruct these concrete prototypical forms. In this study, the Australian female students found this most difficult to undertake. According to Ahsen (1989), concept acquisition is influenced by the way visual images are represented, and for reasons not explored in this study, the Australian female students were more likely to fixate on the North direction being at the top of the page. Ho and Logan (2013) argued that tasks such as the Map Item, which fall outside common examples presented in the classroom, require higher levels of visuospatial thinking, including the capacity to mentally rotate objects on paper or in the mind's eye.

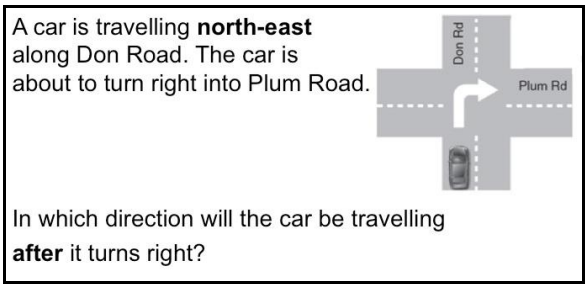


Figure 4. The Map Item (ACARA, 2010b, © Australian Curriculum, Assessment and Reporting Authority, 2010).

Conclusion

The two major findings of the study are associated with (1) country-based performance differences on mathematics items that elicit a specific curriculum or content knowledge; and (2) general performance differences on graphics tasks in favour of males.

The country-based differences could be attributed to curriculum exposure. For the three items that favoured the Singaporean students, content involved knowledge of ratio/proportion; visuospatial techniques; and pre-algebraic thinking. These topics are given more attention in the Singaporean curriculum than in the Australian curriculum in the primary grades. For the Spinner Item, this exposure may be reversed. Consequently, differences between performances on these items may be a result of content/curriculum preference and a particular country's mathematics focus. Nevertheless, these findings are important given the items were developed for the Australian national assessment.

The second finding of the study is independent of curriculum instruction since comparisons were made across gender irrespective of country. The performance differences in favour of males on the Spinner Item may be a result of gender differences in processing visually represented numbers (Bull et al., 2013). As Miller and Halpern (2014) suggested, some gender differences are attributed to the games students play. It is unsurprising that males outperform females on the Map Item given the extensive literature base on the topic (e.g., Lawton, 2010; Lowrie & Diezmann, 2007). Females

typically have a small advantage over males on algebra-based tasks (Else-Quest et al., 2010); however, for the Trees Item, the graphic components of this task (i.e., the diagrams of the trees) may have changed the nature of the task sufficiently to counteract the typical content advantage.

The Singaporean females were less successful in solving the Spinner Item than the other groups. The combination of an unfamiliar topic area and the use of a graphic to represent this topic may have proven challenging. It may also be the case that these students' out-of-school experiences were distinctly different than the other cohorts, which provided challenges in relation to decoding information from unfamiliar tasks. As Logan and Lowrie (2012) suggested elsewhere, females should be provided explicit guidance and support to develop visual recognition skills aligned to locating patterns and objects, for example, subitising and memory games.

There was a significant difference between the performance of Australian males and females on the Map Item (a 47.5% difference). It was apparent that the Australian female students could not re-orient the direction of the map and manage the challenges of aligning a compass bearing to a rotated object. Such Euclidian terminology (e.g., North East, right) is often challenging for females (see Lowrie & Diezmann, 2009), and given there is limited opportunity for exposure to such concepts in the Australian curriculum, this is a topic for further study. By contrast, the Australian males were able to process this information better than all other groups. This would suggest that these differences may not have been a curriculum issue, but rather skill development in out-of-school situations. As Hoffman, Gneezy and List (2011) maintained, the education system is likely to be influential in generating the interaction between society, gender and spatial abilities.

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