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GENDER EFFECTS IN ORIENTATION ON PRIMARY STUDENTS' PERFORMANCE ON ITEMS RICH IN GRAPHICS

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This study investigated the longitudinal performance of 378 students who completed mathematics items rich in graphics. Specifically, this study explored student performance across axis (e.g., numbers lines), opposed-position (e.g., line and column graphs) and circular (e.g., pie charts) items over a three-year period (ages 9-11 years). The results of the study revealed significant performance differences in the favour of boys on graphics items that were represented in horizontal and vertical displays. There were no gender differences on items that were represented in a circular manner.

INTRODUCTION

The burgeoning information age has provided new and increased demands on our capacity to represent, manipulate and decode information in graphical forms. Increasingly, graphs are used to (re)present information and predict trends. Data can be transformed into detailed and dynamic graphic displays with increased sophistication (and ease), and consequently, the challenges faced by students decoding such graphics in school mathematics has changed. The purpose of this paper is to investigate the effect that the orientation of the graphic has on students' ability to decode various visual representations. In particular, we examine the performance of males and females on basic orientation items since there are gender differences (in favour of males) on map items (Diezmann & Lowrie, 2008).

A FRAMEWORK FOR VISUAL PROCESSING

Information Graphics

Visual representations, such as number lines, graphs, charts, and maps are part of the emerging field of information graphics found throughout current school curricula—with such graphics regularly used to represent mathematics content in standardized testing (Logan & Greenlees, 2008). Furthermore, the actual structure and composition of the graphic is generally treated in a single holistic static form rather than the actual elements contained in the graphic (Kosslyn, 2006). Recent studies have shown that the elements (including graph type and structure) contained within a graphics-rich item have a strong influence on decoding performance (see Lowrie & Diezmann, 2005). Consequently, the visual elements (e.g., line, position, slope, area)

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used in constructing a graphic have an impact on how well students understand and interpret the task, and select appropriate strategies and solution pathways.

Mathematical information can be contained in text, keys, legends, axes or labels (Kosslyn, 2006), as well as elements of density and saturation (Bertin, 1967/1983). This information is often represented in multiple forms in any graphic, and thus it is not surprising that young children may find it difficult simply moving between the text of a question and the information in the graphic (Hittleman, 1985). Even with much older college students, individuals tend to read and re-read graphs in order to keep track of the information in the axes and labels (Carpenter & Shah, 1989). With respect to map items, Bertin (1967/1983) argued that a decoder was required to make sense of the linear aspects of parallelism (specifically categories of horizontal and vertical orientation) and the variation of circular systems (e.g., pie charts).

In our previous research (Diezmann & Lowrie, 2008; Lowrie & Diezmann, 2005) we have found that a student's capacity to decode the information embedded in a graphic is demanding in its own right. This is particularly the case when students are required to decode items from standardized tests—with new forms of item representation (rich in graphics)—placing increased demands on cognitive and perceptual processing.

Gender differences on mathematics items

Although most gender differences are attributed to general experiences rather than neurological makeup (Halpern, 2000), males tend to outperform females on spatial tasks (e.g., Bosco, Longoni, & Vecchi, 2004) and particularly mapping tasks (Silverman & Choi, 2006). Diezmann and Lowrie (2008) have suggested that these performance differences are associated with confidence and attitudes toward mathematics and the everyday (out-of-school) experiences that students are exposed to—including increased exposure to technology-based entertainment games.

Saucier et al. (2002) suggested that males tend to utilise Euclidean-based strategies to describe directions and distance when decoding map items—in the sense that they use *directional language* (e.g., north, west, top). By contrast, females tended to use *landmark-based approaches* (e.g., left right, below) to make sense of visual information. In their study it was noteworthy that males outperformed females on tasks that were Euclidean in nature but there were no gender differences on tasks that were represented in a landmark-based form.

The present study goes beyond previous research by investigating basic elements of graphic design (Kosslyn, 2006) by analysing performance on horizontal, vertical and circular elements of graphics that combine to produce map items (Bertin 1967/1983). Moreover, we take note of Fennema and Leder's (1993) challenge to ensure that studies that consider gender differences in mathematics are focused and strategic. To isolate the horizontal, vertical and circular elements of graphics in our study, we selected graphics for investigation which predominately have specific structural properties (e.g., circulare orientation on a pie chart, see Appendix) rather than use map items which contain a multiplicity of orientations.

METHOD

This investigation is part of a 3-year longitudinal study which sought to interpret and describe primary students' capacity to decode information graphics that represent mathematics information. The aims of the study were to:

1. To document primary-aged students' knowledge of graphical items (e.g., number lines, graphs, pie charts) in relation to graphic orientation; and
2. To establish whether there are gender differences in students' decoding performance in relation to graphic orientation.

The Instrument and Items

The 15 orientation items (the five horizontal, vertical and circular-represented items) from the Graphical Languages in Mathematics [GLIM] Test were used in the analysis (for a description of the GLIM test see Diezmann & Lowrie, in press). The GLIM is a 36-item multiple-choice instrument developed to assess students' ability to interpret items from six graphical languages including number lines and graphs. The 15 items varied in complexity, required substantial levels of graphical interpretation and conformed to reliability and validity measures (Lowrie & Diezmann, 2005).

The GLIM orientation items were administered to students in a mass-testing situation annually for three consecutive years. The items were classified in relation to graphic structure. Horizontal items included single axis items (e.g., number lines) and opposed-position items (eg., column graphs) that were represented horizontally. Vertical items included axis and opposed-position items that were vertically orientated. Circular items included connection items (e.g., tree diagrams) and miscellaneous items (e.g., pie charts) which required students to decode information using topographical processing. The Appendix presents two of the items from each of the three orientation categories.

Participants

The participants comprised 378 students (M=204; F=174) from eight primary schools across two states in Australia. The cohort completed the 15 orientation items of the GLIM test each year for three years. The students were in Grade 4 or equivalent when first administered the test (aged 9 or 10). Students' socio-economic status was varied and less than 5% of the students had English as a second language.

RESULTS

Before analysis were undertaken, Guttman's (1950) unidimensional scaling technique was used to determine the suitability of the three orientation categories. The scale, which is validated prior to further data analysis, implies a development sequence for performance of items within a scale. On this scale, values greater than 0.9 are considered to indicate a highly predictive response pattern among items. Values over 0.6 are considered to indicate a scale that is unidimensional and cumulative. The coefficient of reproducibility for the three orientation categories were *horizontal orientation* (.86), *vertical orientation* (.84), and *circular orientation* (.91). The five items contained within each of the three orientation categories were included in the analysis given the strong coefficient measures—since the categories predicted high response patterns among these variables.

The two aims of the study were investigated through an analysis of the participants' responses to the 15 orientation-based items of the GLIM test. These items (the independent variable) were classified as either horizontal, vertical or circular graphical representations (see Appendix). A multivariate analysis of covariance (MANCOVA) was used to analyse mean scores across Grade and Gender dependent variables. A spatial reasoning measure (students' scores on Raven's Standard Progressive Matrices **(**1989**)**) was deemed to be an appropriate covariate [F(2, 1029=150.4, p<.01]. The MANCOVA revealed statistically significant differences between the mean scores of students across both *Grade* [F(6, 2052=24.38, p<.01] and *Gender* [F(3, 1025=10.85, p<.01] variables. There was no statistically significant interaction (*Grade* x *Gender)* [F(6,2052=1.12, p=.35]. Table 1 presents the means (and standard deviations) for grade and gender over the 3-year period.

	Grade 4			Grade 5			Grade 6		
	Total	M	F	Total	M	F	Total	M	F
Hor.	2.75 *(1.16)*	2.92 *(1.11)*	2.55 *(1.15)*	3.19 *(1.23)*	3.44 *(1.20)*	2.90 *(1.21)*	3.44 *(1.14)*	3.56 *(1.14)*	3.31 *(1.12)*
Vert.	*3.45* *(1.11)*	3.58 *(1.07)*	3.29 *(1.15)*	3.89 *(1.05)*	4.04 *(0.96)*	3.71 *(1.11)*	4.14 *(0.93)*	4.24 *(0.91)*	4.02 *(0.94)*
Circ.	2.90 *(1.23)*	2.91 *(1.29)*	2.89 *(1.17)*	3.26 *(1.21)*	3.31 *(1.28)*	3.20 *(1.21)*	3.61 *(1.12)*	3.72 *(1.03)*	3.48 *(1.20)*

Table 2: Means (and Standard Deviations) of Student Scores by Grade and Gender

Student performance increased between 12-16% from Grade 4 to Grade 5 across the three orientation categories. For both the horizontal and vertical categories the increases from Grade 5 to Grade 6 were 6-8%. By contrast the increase for the circular category from Grade 5 to Grade 6 was 11%. Subsequent ANOVA's revealed statistically significant differences in the performance of students across the three years of the study on both *horizontal-orientation* [F(2, 1036=36.38, $p<.01$] and *vertical-orientation* [F(2, 1036=52.92, $p<.01$] variables. Subsequent post-hoc analysis indicated that student improvement was significant across each grade level for each of the two orientation variables.

There were also statistically significant differences between the performance of boys and girls across two of the orientation variables: *horizontal-orientation* [F(1, 1034=24.23, $p<.01$] and *vertical-orientation* [F(1, 1034=14.26, $p<.01$]. For each variable, across each year of the study, the mean scores for the boys were higher than that of the girls. With respect to the vertical-orientation items means scores for boys were between 5%-9% higher than girls while they were between 6%-15% higher on horizontal-orientation items. By contrast there was no statistically significant difference between boys and girls on the *circular-orientation* variable [F(1, 1034=.56, $p=.452$].

DISCUSSION

Our study examined the effect orientation had on the performance of primary-aged students' capacity to decode items rich in graphics. Student performance increased significantly over the 3 year period for both the horizontal and vertical categories. When the graphics were represented in either a horizontal or vertical manner, boys outperformed girls in each of the three years of the investigation. In fact, the mean scores for the boys were approximately twelve months ahead of that of the girls. By contrast there was no statistical difference between the performance of boys and girls on items that were represented in a circular structure. These results go beyond Diezmann and Lowrie's (2008) earlier findings which highlighted gender differences, in favour of boys, on *map* items that required both horizontal and vertical decoding.

We suggest that the performance differences between boys and girls are associated with the way in which items are structured—graphical representations that require vertical or horizontal decoding are, in essence, Euclidean based. Our study has reduced these components to a more fundamental level by analysing the elements of graphical languages that in effect combine to produce maps, namely horizontal, vertical and circular elements. Significantly, there were no gender differences on items which did not contain the linear aspects of parallelism (Bertin, 1967/1983). As Silverman and Choi, (2006) found, females tend to use more holistic typographical approaches to solve graphics tasks, which are effectively employed in the circular items from the GLIM instrument.

CONCLUSIONS

The finding of gender differences in favour of boys on items that contained horizontal or vertical elements has four educational implications. First, everyday instruction in mathematics needs to provide opportunities for girls to become proficient in interpreting (and creating) visual elements in horizontal and/or vertical formats (e.g., graphs, maps and axis items). Such instruction should begin at an early age and the effectiveness of instruction should be monitored as gender differences in mathematics achievement increase over time (Winkelmann, van den Heuvel-Panhuizen, & Robitzsch, 2008). Second, there needs to be a shift in emphasis in the use of vertical or horizontal representations, such as number lines. The finding of gender differences in favour of boys suggest that initially girls need to learn about number lines rather than from number lines. Third, caution needs to be taken in interpreting or creating mathematics achievement tests. Given that items with graphics have a content dimension and a representational dimension, girls may be disadvantaged in a test where the types of graphics are more likely to be solved by boys than girls. Additionally, the content of an item may be masked by its representation. Finally, the literature on orientation and gender effects in mathematics typically focuses on dynamic orientation—a change in orientation. The findings of this study indicate that static orientation of visual elements in graphics is also a fruitful avenue for the exploration of gender differences in maps and other graphics typically used in mathematics.

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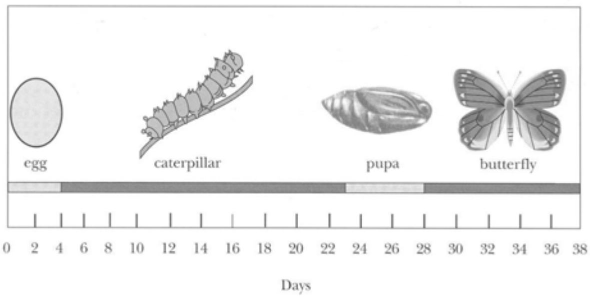
APPENDIX: ORIENTATION ITEMS FROM THE GLIM INSTRUMENT

A. Horizontal Orientation Item[1]

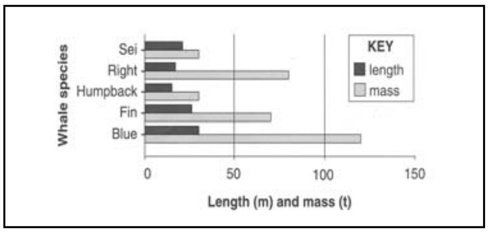
The following graph shows the length of time taken for the four stages in the life of a butterfly.



How many days are there in the caterpillar stage?

B. Horizontal Orientation Item[2]

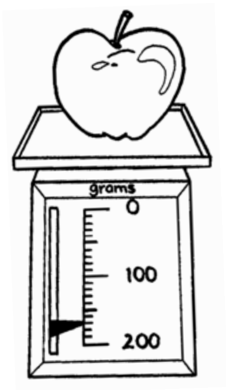
The graph compares the maximum length and mass to which some whales grow.



A fisherman reported that a whale 25 metres long and weighing approximately 80 tonnes had beached itself. Which species of whale could this be?

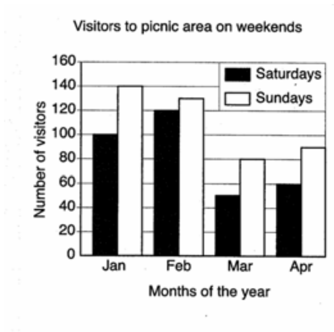
A. Vertical Orientation Item[3]

What is the mass of the apple?



B. Vertical Orientation Item[4]

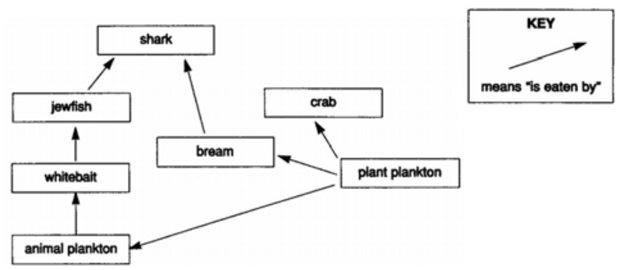
This graph shows the number of visitors to the picnic area for Saturdays and Sundays.



Which month had the most visitors on Sundays?

A. Circular Orientation Item[5]

A simple food web



The animals in this food web eat only what is shown.

If all the animal plankton die which of the following will also die?

B. Circular Orientation Item[6]

In 2003, Jemma budgeted $30 on clothes.
Approximately how much money did she get that year?