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Understanding graphicacy: Students' making sense of graphics in mathematics assessment tasks

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Abstract

The ability to decode graphics is an increasingly important component of mathematics assessment and curricula. This study examined 50, 9- to 10-year-old students (23 male, 27 female), as they solved items from six distinct graphical languages (e.g., maps) that are commonly used to convey mathematical information. The results of the study revealed: 1) factors which contribute to success or hinder performance on tasks with various graphical representations; and 2) how the literacy and graphical demands of tasks influence the mathematical sense making of students. The outcomes of this study highlight the changing nature of assessment in school mathematics and identify the function and influence of graphics in the design of assessment tasks.

Key Words

Graphical tasks

Information graphics

Mathematics sense making

Assessment

UNDERSTANDING GRAPHICACY: STUDENTS' MAKING SENSE OF

GRAPHICS IN MATHEMATICS ASSESSMENT TASKS

Introduction

Our society is becoming more reliant on the representation of information in graphical forms as traditional communication and literacy demands change and adapt to what could be considered a burgeoning information age (Leu, Kinzer, Coiro, & Cammack, 2004). The access that individuals have to digital technologies seems limitless and as such, "seems to provide optimal conditions for graphs and diagrams to be used as tools for presenting information" (Stern, Aprea, & Ebner, 2003, p. 192). Hence, the collation and presentation of information is becoming increasingly visual and spatial in nature. At the same time, there is renewed debate regarding the approaches that schools should take to ensure the development of a numerate society who can effectively engage with and understand the practical mathematical demands of everyday life (e.g., National Council of Teachers of Mathematics [NCTM], 2000; Steen, 1997). There is a strong case for the view that "numeracy also demands practical understandings of the ways in which information is gathered by counting and measuring, and is presented in *graphs, diagrams, charts* and *tables* (emphasis added)" (Department for Education and Employment U.K., 1998, p. 110). Recent studies have argued that today's primary-aged students are more likely to encounter assessment tasks that contain graphics than in the past (Gagatsis & Elia, 2004; Lowrie & Diezmann, 2009; Yeh & McTigue, 2009). This investigation is timely due to the fact that high-stakes testing has heralded a new era in school assessment. New forms of accountability and an increased emphasis on national and international standards (and benchmarks) not only have the potential to reshape school curricula but also have broader ramifications for students and teachers (Jones & Egley, 2007). The scope of this paper is to determine whether the design of mathematics items are more likely to be a reliable indication of student performance if graphical, contextual and literacy elements are considered both in isolation and in integrated ways as essential aspects of task design. This research does not advocate "teaching to tests" but rather presents an investigation which considers the extent to which *new* assessment items (which have higher graphical demands) influence students' sense making (Lowrie & Diezmann, 2009).

Graphical Tasks in Mathematics

In this study, the term 'graphical tasks' is used to describe those items specifically used in this study, that is, mathematics assessment items which contain a graphic which is deemed to be integral to the solution process. The purpose of this study is to identify the task elements that either promote or hinder sense making when students solve graphical tasks—and indeed consider the interplay between these elements as students' make sense of these tasks. The graphical elements include the graphic, the mathematics content (including the task context) and the associated literacy demands.

The Graphic

Graphics are defined as visual representations for "storing, understanding and communicating essential information" (Bertin, 1967/1983, p. 2) and include graphs, maps, number lines, and flow charts. They play a dual role in mathematics tasks and involve information and contextual graphics or what Gagatsis and Elia (2004) term autonomous or auxiliary graphics respectively. Information or autonomous representations contain information essential to the task which is not presented elsewhere (i.e., in text or symbols). By contrast, an auxiliary or contextual representation contains information that might be helpful in problem solving (e.g., providing a cue to the context) but is not essential to solution.

In order to decode a graphic, an individual must contend with multiple sources of information which may include text, keys or legends, axes, and labels (Kosslyn, 2006), as well as perceptual elements of retinal variables (e.g., depth of shading and pattern) (Bertin, 1967/1983). In most standardised mathematics instruments it is often necessary to consider these interrelated components in conjunction with the actual mathematics that is contained within a given task. Studies by Hittleman (1985) and Carpenter and Shah (1998) have shown that students find it challenging to move between text and graphics to the extent that it can disturb their thinking. Research suggests that the graphic can make the task more difficult to decode (Berends & van Lieshout, 2009; Elia, Gagatsis, & Demetriou, 2007; Schmidt-Weigand, Kohnert, & Glowalla, 2010). In any given mathematics task, the degree of difficulty students experience could be due to the complexity of the graphic, the mathematics content or the literacy demands associated with the task (Lowrie & Diezmann, 2009).

Specific graphics can have a strong influence on students' success even when the graphics are informationally equivalent, indicating that the graphic representation does matter (Baker, Corbett, and Koedinger, 2001). If students are not able to access and interpret the information effectively, the actual mathematics embedded within a given graphics task is not likely to be influential in the solution. As a result, students may disregard some of the information in graphics, rather than utilising them to their full capabilities (Schnotz, Picard, & Hron, 1993).

Graphical elements influence task complexity. Roth (2002) argued that the difficulties exhibited by students reading mathematical formulae and graphs may occur not because of 'misconceptions' or cognitive 'understandings', but rather because they are unfamiliar with the content domain and conventions regulating sign use. When readers are very familiar with the signs and symbols within a task, these graphical elements may potentially be 'glazed over'. These elements provide the spatial framework that helps organise information and the particular conventions that represent information. The problem solver may pay less attention to the various graphical elements within the graphic and thus disregard necessary graphical structures (e.g., the segments in a pie chart). Readers are required to be familiar with and understand the mathematical purpose and situations for which such conventions are constructed and the extent to which contextual meaning (and experiences) influence the interpretation of the graphic.

Mathematical Content and Contexts

The interpretation of graphics requires consideration of the mathematical content and the context. Curcio (1987) argues that the mathematical content of a graph involves the numbers, their relationships, and the operations with numbers represented on the graph. The context is the mathematical situation in which the task is framed. These relationships can be exemplified through a description of a typical mathematics task.

A box contains 4 blue marbles, 10 red marbles and 6 yellow marbles.

Which colour marble is **impossible** to take from the box?

   Red   Blue   White   Yellow

The graphic for this question would typically be represented as a box with various coloured marbles displayed within the box. These marbles may well be coloured or labelled (typically in a key) by colour. The context of this question involves the notion of a realistic scenario in the sense that you are required to determine whether you can

"find" the respective marbles in the box. The context, therefore, is based on the premise that it is impossible to take White marbles out of the box because there are no White marbles in the box.

The way in which mathematical content is presented may impact on a problem solvers initial sense of a task, leading to the use of routine and highly practiced responses. As such, students may pay only superficial attention to the written text within a task, finding key words which may indicate important information relating to the graphic. This can limit students' holistic understanding of the task, and hence, the rationality and correctness of their answers (Wiest, 2003). Moreover, "many mathematics problems require students to suspend reality and ignore their common sense in order to get a correct answer" (Boaler, 1994, p. 554).

As Cooper and Dunne (2000) maintained, many students attempt to solve tasks set within a 'realistic' context as if they are not 'realistic' at all. They argue that there is often a blurring of the boundary between tasks that demand or do not demand a realistic solution and that those students often bring their own experiences to the contextual situation. When solutions require a single 'correct' response (as is the case with multiple choice tasks) the opportunity to interpret the task from a realistic perspective may be less problematic. However, as Lowrie and Diezmann (2009) suggested, realistic intentions and impressions may result in an incorrect interpretation of the task if students give preference to information from their experiences in favour of information from the graphic.

Literacy Demands in Mathematics Tasks

A major issue in interpreting and reading mathematic graphical tasks is the multiple meanings represented in the accompanying written text. The multiple layering of 'meaning' is also applied to the use of language in everyday contexts and interactions (Adams, 2003). The issues associated with multiple meanings become somewhat more problematic when working with primary-aged children. As Berenson (1997) maintained, "the pre-adolescent child has multiple meanings for words used in the interactions and is comfortable with moving between meanings even in the same interaction" (p. 4). Thus, language used in out-of-school contexts has the potential to confuse students' understanding of mathematics, where they fail to differentiate between the mathematical meaning and the everyday meaning (MacGregor, 2002). Assessment items designed in a relatively authentic or realistic manner may prove

challenging as the problem solver is confronted with the choice of making connections with prior knowledge of the real-world context or analysing the task within the mathematical context boundaries. Mathematical tasks use language that is also used in everyday contexts (for example, 'volume' and 'net') and for some students, the dual mathematical-everyday use of terms may potentially cause difficulties (e.g., Zevenbergen, 2000).

The Categorisation and Hierarchy of Information Graphics

A body of literature has indicated that even the most routine analysis of data that is embedded in graphics may be difficult for primary-aged children (Doig & Groves, 1999), older children (Preece, 1993), university students (Goldberg & Anderson, 1989), and even professionals (Roth & Bowen, 2001). As Postigo and Pozo (2004) suggested, "students restrict themselves to reading data and processing specific aspects of the material and encounter problems when they have to go beyond this elementary level and interpret the information represented" (p. 628). Since students encounter a diverse range of graphs—in both school and out-of-school contexts—difficulties may arise in their capacity to interpret and read between (and beyond) the data. A current curriculum document states it is "important for students to reflect on their use of representations to develop an understanding of the relative strengths and weaknesses of various representations for difference purposes" (NCTM, 2000, p. 70). To understand the complexities of interpreting graphics, it is necessary to appreciate the different graphical forms to which students are typically exposed.

Mackinlay's (1999) model of graphical languages was selected as the theoretical framework for the study because it provides a perceptual basis for analysing students' understanding of mathematical items. It provides scope to categorise graphics within a visual and spatial domain and lends itself well to current thinking about how students create and decode graphics to both organise and communicate mathematical ideas. Mackinlay describes six types of graphics representation in the following ways (see Table 1):

Table 1

Structure and Functionality of the Six Graphical Languages

Graphical languages	Graphical knowledge	Mathematics functionality
Axis (e.g., number line)	Relative position of a mark on an axis.	Number line as a measurement model
Apposed-position (e.g. graph)	Relative position of marked sets of points between two axes.	Representation of quantitative data
Retinal-list (e.g., flip)	Conventions in using colour, shape, size, saturation, texture, or orientation in representation. Markings are not dependent on position.	Translations, rotations, reflections, discrimination skills
Map	Model of spatial representation of locations or objects and the convention of key use.	Bird's-eye view, 2D-3D representations
Connection language (e.g., family tree)	Conventions of structured networks with nodes, links and directionality.	Everyday applications (e.g. train maps, knockout competitions)
Miscellaneous (e.g., pie chart)	Conventions of additional graphical techniques (e.g., angle, containment) in representation.	Various depending on the graphic, including proportion

(Adapted from Lowrie & Diezmann, 2005, p. 266)

Mackinlay's (1999) framework provides scope for the analysis of different forms of graphical representations that are commonly encountered by students in assessment situations. Examples of the six graphical languages are included in the Appendix.

Design and Method

This investigation is part of a 4-year longitudinal study in which we are monitoring the development of primary students' ability to decode the six types of graphical languages. This study examines the cohort involved in the qualitative component of the larger study. Grade 4 students' performance and interview responses on a set of 12 graphical tasks found in mathematics standardised instruments were analysed. Students' performance and responses were investigated through the following two research questions:

1. What aspects of a graphical task influence successful performance?
2. What elements influence students' sense-making on graphical tasks?

The first research question considers students' success on tasks and the extent to which their understandings (or lack of) influenced performance. The second research questions examines the elements of a task including the graphic, the mathematics content and context and the literacy demands with the specific tasks.

Participants

This study involved 50 participants (23 male, 27 female) aged 9- to 10-years-old students from three primary schools in a large regional city. The three schools involved consisted of one government, one Catholic and one independent school and they all catered for children aged 5-12 years (Kindergarten to Grade 6). Situated in a large regional city with a population of over 50 000, these medium-sized schools all had enrolments of over 200 students. The schools were randomly chosen from a convenience sample within a practical distance from the University. Given the diversity of the school environments, the participants were from varying socioeconomic and academic backgrounds, and reflected the ethnic and cultural composition of the local community, with less than 5% of the students speaking English as their second language. The participants were randomly selected across the classes and could be described as relatively monocultural with students typically from an Anglo Saxon background. Verification with teachers indicated that the participants were of mixed academic ability.

Interview Items

The set of 12 interview items consisted of one pair of items from each of the six graphical languages. These items were selected from Grade 4 state and national tests and thus were considered age and grade appropriate for this study and were drawn from the 36 item Graphical Languages in Mathematics [GLIM] instrument (see Diezmann & Lowrie, 2009 for an extensive summary of how the Instrument was designed). These 36 items were organised into three sets of age-appropriate items comprising two items from each graphical language. Set 1, which were the focus of this study, was comprised of the Grade 4 items from each of the six types of graphics presented to the students.

The mathematics items contained in this instrument are typical of the tasks students of this age encounter in formalised testing. We do not suggest that these items are exceptionally-well designed but rather have typical representation and structure. Moreover, the participants may have encountered these types of graphics previously during instruction, in the use of textbooks, or in assessment tasks. To our knowledge, none of these students has received overt instruction about how to decode these types of graphics because neither the state mathematics syllabus nor the school mathematics programs included a specific focus on learning about graphics. In fact, the most likely encounters with such items would be associated with the implementation of state and national testing.

The Interview Design and Framework

Each participant's interview took place over two days, with students completing six tasks each day. The timing was to minimise any effects of fatigue on students. In the interviews, two tasks from each of the six graphical languages were presented to the students in turn. Thus, in the first interview, students were asked to solve two Axis, two Apposed-position and two Retinal-list tasks. In the second interview, students were presented with two Map, two Connection and two Miscellaneous tasks (see Appendix). Thus, over the two days they had responded to all twelve tasks of the booklet over the two interviews.

In each interview, after participants had completed two tasks from each of the languages, semi-structured interview questions were posed. These questions were designed to support students to explain their thinking and the strategies that they had used to solve the tasks. The semi-structured questions included:

- Can you tell me how you worked out the answer?
- What information was there on the diagram that helped you work out the answer?
- How does it tell you that information?
- Tell me what you did to work out the answer.
- Please tell me a bit more about that.

The interview data were analysed within an inductive theory-building framework with a focus on description and explanation (Krathwohl, 1993) to identify the strategies that students used in task solution and the difficulties they encountered with particular reference to the graphic in the task. The tactics for generating meaning were noting

patterns and themes, imputing plausibility, and building a logical chain of evidence (Miles & Huberman, 1994).

Three categories were considered (in the first instance in isolation) in order to create a framework that would provide opportunities to appreciate the sense making that takes place when children are involved with solving mathematics problems with embedded graphics. These categories were: 1) the graphic; 2) the mathematical content and contexts; and 3) the literacy demands in mathematics tasks. These three categories were initially considered as separate identities, however, the complexities associated with sense making require these elements to be considered in tandem. These three categories were used as 'lenses' that helped us describe the way in which the students interpreted the graphic and constructed meaning from the mathematics task. Within this context, we considered factors that enhanced or inhibited task success and mathematical sense making, specifically focusing on the knowledge utilised and the difficulties faced when decoding graphical tasks.

Results and Discussion

The analysis of students' performance on graphical tasks provides insight into critical aspects of the decoding process. Specifically, we identified elements of graphics tasks that supported or hindered successful completion; highlighted the knowledge that students use in the decoding process; and described the difficulties that students encounter in this process.

What Aspects of a Graphical Task Influence Successful Performance?

This section addresses the first research question by focussing on tasks which a high proportion of students answered correctly. On each of the four easiest items, which are discussed shortly, at least 90% of students' responses were correct (see Table 2). However, there were distinct differences in the performance of participants across the 12 graphical problems (see Appendix) with mean scores ranging from .98 to .32 on individual items within the test.

Table 2

Means and Standard Deviations for the Twelve Mathematical Items (N =50) in Descending Order of Difficulty

Language	Item number (see Appendix)	Mean	S.D
Retinal-list	6	.32	.47
Retinal-list	5	.40	.49
Apposed-position	4	.54	.50
Miscellaneous	12	.66	.48
Axis	2	.72	.45
Axis	1	.74	.44
Connection	10	.70	.46
Map	8	.74	.44
Apposed-position	3	.90	.33
Connection	9	.94	.24
Miscellaneous	11	.94	.24
Map	7	.98	.14

Jasmine's Desk Item

This Map item (see Appendix, Item 7) required the students to interpret multiple representations pertaining to space and location, and yet this was the easiest task for the participants to complete (98% answered correctly). Students usually have difficulty in effectively solving tasks with multiple coordinated representations (Brna, Cox and Good, 2001) however the ease of the task also needs to be considered. Ainsworth, Wood, and Bibby (1996) highlighted the fact that, under certain circumstances, it would seem that these multiple representations could 'act against' each other. There were a number of factors that made Jasmine's desk item easy for students to interpret. Although the item was presented from a bird's-eye view, there were no overlapping elements and there was no requirement to re-orientate the graphic to answer the question.

> Elise: The glue is the circle—top right hand corner. The ruler is next to the glue, the book is in the bottom left hand corner and the pencil case is next to the book.

This task simply involved the one-to-one correspondence of simple shapes representing familiar objects. For this item, most students were able to decode the

graphical information which essentially involved two 2D representations of a 3D situation.

The Temperature Item

The Miscellaneous item (see Appendix, Item 11, 94% correct) involved the identification and matching of scales (of a temperature recording) on two different representations. We anticipated this would be difficult for students because Baker, Corbett and Koedinger (2001) found large variations in students' ability to identify informationally equivalent representations. Baker, Corbett and Koedinger (2001) reported substantial variance in eighth- and ninth-grade students' ability to interpret informationally equivalent graphics with students' comparative success rates of 95% on a histogram, 56% on a scatterplot, and 17% on a stem-and-leaf plot. They argued that this performance variance was due to students' transfer of knowledge about bar graphs to the other three graphics, and that although histograms and scatterplots share surface features with bar graphs, stem and-leaf plots vary at the surface level from bar graphs. Hence, we expected that matching the representation of thermometers using a vertical scale and a circular scale would be difficult for students of this age. Although reading a vertical scale was likely to be familiar to students as this is a common type of thermometer, reading a circular scale was likely to be novel since this thermometer was represented in an unusual way. As one student suggested:

> Terry: it would be easier if the question was like a speedo in the car,
> because most kids have seen them before.

Terry found it difficult appreciate that a thermometer (and hence temperature) could be represented in a circular manner. By contrast, other students were able to make the connection between an axis and circular thermometer representation because they related it to the characteristics of a clock face. For example, when Rachael described how she made sense of the circular representations, she talked about the arrows as hands in order to determine an accurate reading. Other students used clock analogies in their solution explanations with words and phrases like 'past', 'past 20 and before 21', 'pointing to 21'. These phrases are often used when children are being taught how to tell the time.

The Hum Item

The Connection item (see Appendix, Item 9, 94% correct) was framed within everyday contexts however, the intent of the task was for students to use mathematics processing to navigate a flow-chart representation. Despite the very high success rate, the "realistic" nature of the task provided some students with the opportunity to use prior knowledge and experiences to complete the task rather than utilise the graphic. Thus, some students' familiarity with the concept of 'sound' proved to be highly influential, as they drew on past experience and overlooked the graphic in selecting their response.

> Lorraine: I chose low and soft [the correct response] because a hum goes
> low not high and hums are mostly soft not loud.

When working out his answer, one student decided not to consider the left-hand side of the graphic.

> Jason: Hums aren't loud [but indicated that the question was confusing
> because] some people do hum loud.

Another student used a combination of general knowledge and the graphic.

> Rachael: I thought of a hum in my head and what it sounded like…
> [and] it was underneath low and soft.

Other students relied completely on general knowledge to correctly solve the item.

> Teneal: I remember humming to my baby cousin.

Those students who used the graphic tended to start at its base and followed the path upwards from the term 'hum'.

> Gemma: I found hum and followed the line going to soft and then the
> line going across and up to low.

> Justin: I saw hum down the bottom, looked up and saw soft, thought
> maybe soft and loud but that wasn't an option so looked up
> again and saw low.

Based on the variety of response, it would be misleading to infer that students had an adequate understanding of how to solve tasks using connection graphics. Students' familiarity with a context can have a positive effect on emotions and memory in situations where they are re-exposed to the context (Monahan, Murphy, & Zajonc,

2000), however previous exposure changes the way the perceiver subjectively experiences the stimulus (Smith, 1998). This familiarity has the affect of distracting the individual from objectively undertaking a task to responding more subjectively based on prior experience.

The Picnic Area Item

This Apposed-position item (see Appendix, Item 3, 90% correct) required students to read and compare bars on a graph. The correct response was the tallest bar on the graph—as is typically the case in textbooks, teacher demonstrations and testing items with students at this age level. Of the correct responses, 22% of students simply selected the correct answer because it was the tallest bar. Hence, students' proficiency with this graphical representation was unclear because their success was in part due to an automated response rather than their knowledge of an Apposed-position graphic.

> Sarah: January has the most visitors because the white line is bigger than all the rest.
>
> Lorraine: January has the most people because it is bigger than all the others.
>
> Terry: That [January] is the tallest column, the rest are all shorter. I looked at the key but didn't really pay much attention just chose the tallest column.

Although exemplars are useful in mathematics for presenting a summary representation encapsulating the salient properties of a category (Varela, Thompson, & Rosch, 1993), they can limit the scope of students' conceptual understanding. This outcome was also the case for Item 4 (also an Apposed-position language item) where the majority of students (58%) selected an incorrect response primarily because it was the tallest bar in the graphic. Repeatedly asking students to identify the 'tallest' bar could lead to a form of automaticity in which the graphic, and the information embedded within, essentially is overlooked.

What Elements Influence Students' Sense-making on Graphical Tasks?

The second research question considered the impact task elements had on performance, and focused on the manner in which the students made sense of the respective items in the instrument. As previously discussed, the six graphical languages share common features, but nevertheless elicit different solution strategies and specific graphical knowledge in order to decode and solve tasks. Table 3 outlines student performance in relation to task correctness and also identifies the most common correct and incorrect strategy used to solve the respective tasks. The most influential element of the task was determined through an analysis of the most common strategy or form of behaviour exhibited by the students as they solved the task. This was the case for both correct and incorrect solutions and thus the task element represented the element of the task that was most influential in students' interpretation of the task.

Table 3

Performance success by task, most common strategy used and most influential task element

	Total Correct (C) and Incorrect (In)	Most prominent code	No. of students using strategy (%)	Task element
1	C=37	Located letter closest to 20	26 (70%)	Graphic
	In=13	Did not understand what the letters represented	9 (69%)	
2	C=36	Chose option to the right/past/after 1 on line	9 (25%)	Graphic
	In=14	Inaccurate position	12 (86%)	
3	C=45	Used key and chose tallest bar	39 (87%)	Graphic
	In=5	Misread the graphic	5 (100%)	
4	C=27	Used text and chose shortest bar	21 (78%)	Literacy
	In=23	Did not consider text & chose tallest bar	23 (100%)	demands
5	C=20	Matched piece to puzzle	14 (70%)	Graphic
	In=20	Inappropriate matching	20 (100%)	
6	C=16	Imagined the action of flipping	11 (69%)	Literacy
	In=34	Inappropriate flipping	28 (82%)	demands
7	C=49	Matched position of items	41 (84%)	Graphic
	In=1	N/A		
8	C=37	Followed set directions	36 (97%)	Literacy
	In=13	Counted landmarks	5 (38%)	demands
9	C=47	Followed path/line	39 (83%)	Context
	In=3	Used prior knowledge	3 (100%)	
10	C=35	Used keys and arrows to follow path	19 (54%)	Context
	In=15	Misread the arrows / used prior knowledge	11 (73%)	
11	C=47	Located information on scales	47 (100%)	Graphic
	In=3	Vague responses	2 (67%)	
12	C=33	Used key and compared portions	26 (79%)	Literacy
	In=17	Unable to match words to graphic & chose most shaded area	16 (94%)	demands

Although the identification of relatively specific graphical 'structures and functions' (see Table 1) provided scope for analysis, the manner in which students interpreted and solved individual items within each language had to be addressed. As a consequence, all of the transcripts were analysed across items as well as within each language. Interview transcripts were coded in relation to student responses with video analysis used to complement these data. This ensured that we could ascertain what aspects of the task most influenced the students' mathematics processing. In most

instances, the students predominantly utilised the graphic to solve the task. Given the nature of the tasks, this was to be expected.

The Graphic

For each item, we were able to isolate the graphic demands, and the other aspects of the task (namely the content/context and literacy demands) as the participants employed a range of strategies to solve the task. For five of the items (Items 1, 2, 3, 5, and 11) students' capacity to decode the graphic was the most influential element in task success (see Table 3). For these items, the context and other literacy demands were less influential.

From a conceptual perspective, the students found it easier to decipher information when the spatial representations required matching and comparing rather than the transformation or rotation of objects (e.g., see Appendix, Item 7 as opposed to Item 6). Some of the items in the instrument required students to move beyond relatively simplistic interpretation of the graphic by establishing connections between numerous aspects of the problem and thus make inferences from information provided. For example, 46% of students were unable to consider the inverse relationship between variables on one of the Apposed-position items (see Appendix, Item 4). This item required strong connections to be made between the nature of the graphic and application of the content in the written text. The specific content knowledge (which has science-based foundations) needed to be considered with the graphic representation in order to solve the task. This is in contrast to Item 3 (the Picnic task) which could be solved predominately by looking at the graphic.

Students' responses were derived from their everyday knowledge of graphics. Thus, general applications tended to span most of the graphical languages—with students appreciating that the graphics were represented in different scales, perspectives and orientations. However, an *over familiarity* with specific mathematical language, terminology or context influenced not only success but the attention given to the graphic embedded within the item.

Content and Context

Items that were based fundamentally on realistic scenarios had the potential to draw students' attention away from the actual graphic and allowed them to use

general, out-of-school knowledge to complete the task. This was particularly the case with the two Connection items (see Appendix, Items 9 and 10). At times, this knowledge became overly influential and the mathematics and graphic in the task were overlooked as students used their everyday knowledge to complete the items without considering all of the information. Nearly a third of students (30%) were strongly influenced by 'life-like' content of the items, with approximately half (47%) of these students distracted by this information. Given the plausibility of the choice of options presented in Item 9 [options were: a) high and loud; b) high and soft; c) low and loud; and d) low and soft] and Item 10 [options were: a) snails and snakes; b) frogs and snails; c) insects and snails; and d) snakes and insects], it was possible for students to choose a correct answer relying solely on general, out-of-school knowledge. As an example of this, in the first connection item, (see Appendix, Item 9) students responded:

> Geraldine: Usually when you hum it is low and soft.
>
> Angela: [vocalizing the hum sound] I chose that one [low and soft] because it is the closest [to what a hum sounds like].

For the second Connection item (see Appendix, Item 10), a number of students relied solely on their out-of-school or general knowledge in choosing the correct answer.

> Ian: I just knew that birds eat snails and insects, I didn't use the diagram.
>
> Jason: Snails and insects are small and birds can pick them up.

However, it was also possible to choose an incorrect answer using this same process. Three of the respondents commented that they just thought birds eat 'frogs and snails', or they have seen birds eat 'snakes and insects'. For example:

> Geraldine: I just thought about what some birds eat and thought frogs and snails.
>
> Kate: When I have looked at a bird before they've had frogs and snails, I have seen them.
>
> Sarah: I just thought birds would eat snakes and insects.

Such familiarity with task context can lead to situations where the problem solver does not interpret or decode the graphic—rather selecting a solution that intuitively 'makes sense'.

Mathematics Literacy Demands

On occasions, the interpretation of specific mathematical terminology was influential in how students made sense of the graphics. The most difficult interview item, which was a Retinal-list item (see Appendix, Item 6, 32% correct), asked "Which two faces show a flip?" Although the term 'flip' is part of the students' mathematics curriculum, it had dual meaning—in the sense that it related to a word that is part of their day-to-day vocabulary or everyday usage. A high proportion of students (56%) were confused by the term 'flip' but demonstrated the capacity to rotate two-dimensional representations. Many of the students thought that the concept of a 'flip' was associated with rotating an object 180° rather than the reflection of an object along an axis of symmetry.

Tammy: [A flip is] upside down and right way up.

Angela: A flip is upside down. One face is up and one face is down.

To make sense of the item, students called upon prior knowledge of the word 'flip'. This knowledge was often based on out-of-school experiences associated with day-to-day activities like flipping over a card.

Lachlan: You do a flip into a pool, going upside down.

These students' responses highlighted how easily the disjunction between the mathematical and everyday use of a term can impact negatively on students' performance.

The mathematical language embedded within some of the items affected task performance. In two items (see Table 3), the complexity of the written information (e.g., Item 4) or unfamiliarity of the words (e.g., Item 12) created misunderstandings. These two items had success rates of 54% and 66% respectively, and were the third and fourth most difficult items. Students had difficulty connecting the written information within the item to the graphic and thus the linking of information from these two aspects was diminished.

It was certainly the case that tasks which contained 'realistic' or authentic contexts created a degree of layering that generated multiple (and false) meanings outside the intended scope of the task. Thus, the context and language have acted as a

distracter because the mathematics ideas (and the 'intended' processes for solving the task) were not evoked.

Conclusions

Primary students are increasingly required to interpret mathematics tasks that are rich in graphics with such 'task representations' now common in standardised tests. The increased use of graphics adds another layer of interpretation to a given task requiring the co-ordination of disparate aspects of the task in order to produce a correct solution. The results of this study demonstrate that many errors and misunderstandings on standardised items could be attributed to an inability to decode the graphic embedded within the task. By considering the different graphic elements that constitute a task (Kosslyn, 2006), we were able to identify which aspects of a standardised item most influences student performance.

The Retinal-list language items proved to be the most difficult for students to solve. We maintain that these items demanded the solver to pay careful attention to either the graphical elements (Item 3) or the literacy demands (Item 4) of the tasks as they had to discriminate between graphical information that varied (only) slightly in representation. By contrast, the easier items required the matching of certain graphical elements on a one-to-one basis such as matching the glue pot (3D object) to the circle and so on. As a result, the interpretation of the graphical tasks was not necessarily considered holistically. For example, on Items 7 and 11 students tended to isolate objects within the graphic in order to complete the task, whereas with the Retinal-list items, students needed to consider the graphics and other information simultaneously to solve the task. As Preece (1993), and Goldberg and Anderson (1989) argued, even older students find it difficult to move between different components of a task (e.g., from the graphic to the text and back to the graphic) when solving a problem.

Misunderstandings arose when one element of the task (whether it be a word or an aspect of the graphic) disrupted reasoning to such an extent that important information pertaining to the task was overlooked. In particular, words (and thus the literacy demands) had multiple meanings and were complex in nature or unfamiliar. In such cases, the graphic did not provide the students with complementary (or additional) information to scaffold thinking or realign conceptual misconceptions.

Difficulties also arose when contextual information was considered apart from the collective information presented in the task. On the two Connection items (Items 9

and 10), for example, nearly a third of students ignored the graphics in the tasks and based their answers on knowledge of everyday events or an intuitive understanding of what information was presented (Boaler, 1993). Lowrie (2000) found that when students encountered mathematics tasks with high visual or spatial demands, realistic scenarios caused confusion if students were not willing (or able) to internalise all information presented. Incorrect responses occurred when student's personal experiences disrupted the problem-solving process. In the present study, necessary information was ignored if students selected solution pathways that appeared realistic or sensible to them (based on personal experiences).

With some of the more difficult items, an ability to make connections between the graphic, the mathematics content/context and the literacy demands was essential. Those students who focused on one aspect of the graphic (e.g., a word or a context experience), without considering the connection between all graphical elements, were distracted by (mis)information. By contrast, those students who were able to consider the graphic representation, in its entirety, were able to use cues to make sense of the mathematics tasks.

When students are learning to decode graphical tasks, all graphical elements (such as text, keys or legends, axes and labels) need to be addressed. Since specific graphics have different function and form, the relationship between the graphic, the mathematics content and the literacy demands can be variously influential. Apart from the Retinal-list language items, students in this study did not find graphics within a particular language to be any more difficult to solve than others. Nevertheless, we argue that it is necessary for classroom teachers to explicitly identify the attributes (and differences) among the respective graphical languages since many of the students' incorrect responses were due to the fact that important graphical features were overlooked.

This study highlights the problematic nature of assessment items in a high-stakes testing era. The abundance of graphics in mandatory tests is a relatively new phenomenon (Lowrie & Diezmann, 2009) with this study showing the influential nature of graphics in the responses students select. Many of the graphic elements within these tasks scaffolded the students' mathematical understanding rather than being an essential component of the task from which to assess mathematics performance. By contrast, the graphic elements in other tasks actually disrupted students thinking to such an extent that the mathematics concepts were neutralised.

We maintain that it is essential that poorly constructed graphical tasks do not impact on performance and consequently the graphic needs to be carefully chosen to ensure the integrity and meaning of the item is maintained (Diezmann, 2008). This study demonstrates the need to construct mathematics test items from an 'holistic design' perspective which considers the entire representation—and hence the relationship between the graphic, the mathematics content (and context) and the surrounding literacy demands—which is an avenue for further research.

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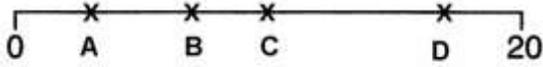
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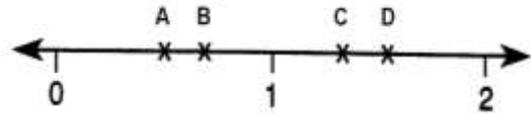
Appendix

Graphical Language Tasks from Interview

Estimate where you think 17 should go on this number line.

Answer			
☐ A	☐ B	☐ C	☐ D

Item 1, Axis (Adapted from QSCC, 2000a, p. 11.)

Estimate where you think 1.3 should go on this number line.

Answer			
☐ A	☐ B	☐ C	☐ D

Item 2, Axis (QSCC, 2000b, p. 8.)

This graph shows the number of visitors to the picnic area for Saturdays and Sundays.
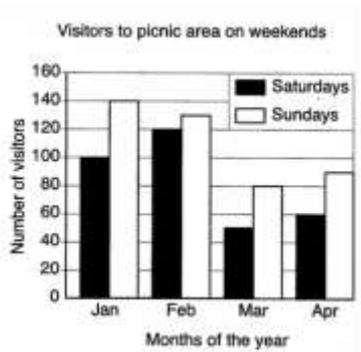
Which month had the most visitors on Sundays?

Answer			
☐ Jan	☐ Feb	☐ Mar	☐ Apr

Item 3, **Apposed-position** (QSCC, 2000c, p. 9.)

Syrups are thick, sticky liquids. The thicker the syrup, the slower it will move down a slope.

The graph shows the distance four different syrups moved down a slope in one minute.
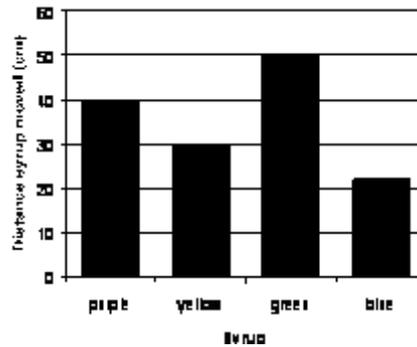
Which syrup is the thickest?

Answer	
☐ Blue	☐ Green
☐ Yellow	☐ Purple

Item 4, Apposed-position (Adapted from NSW Educational Testing Centre, 2003, p.3.)

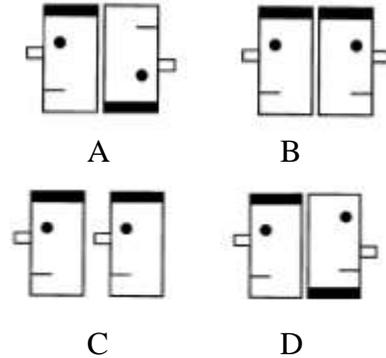When the last piece is put into the puzzle it shows 3 triangles.
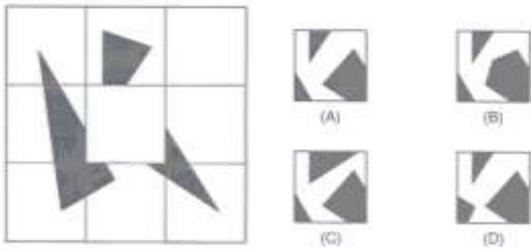
Which piece is missing from this puzzle?

Answer			
☐ A	☐ B	☐ C	☐ D

Item 5, Retinal-list (Adapted from NSW Educational Testing Centre, 2002a, p. 8.)

Which two faces show a flip?

A   B

C   D

Answer			
☐ A	☐ B	☐ C	☐ D

Item 6, Retinal-list (Adapted from QSCC, 2001, p. 13.)

Jasmine has a book, ruler, pencil case and glue on her desk.

Which map best shows where everything is on Jasmine's desk?

Answer			
☐ A	☐ B	☐ C	☐ D

Item 7, Map (Adapted from NSW Educational Testing Centre, 2002b, p. 4.)

Ben went from the gate to the tap, then to the shed, then to the rubbish bins.

How many times did he cross the track?

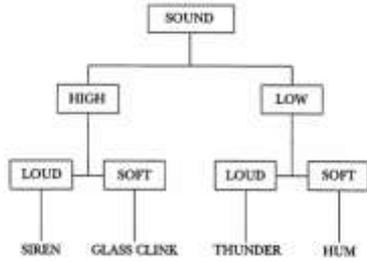| Answer			
☐ 1	☐ 2	☐ 3	☐ 4

Item 8, Map (QSCC, 2002, p.11.)

This flowchart shows a way to describe sounds.


Which of the following describes a 'hum'?

Answer
☐ high and loud   ☐ high and soft
☐ low and loud   ☐ low and soft

Item 9, Connection (NSW Educational Testing Centre, 2001, p. 3.)

This diagram shows what some animals eat.

What are some of the animals that these birds eat?

Answer
☐ snails and snakes   ☐ frogs and snails
☐ insects and snails   ☐ snakes and insects

Item 10, Connection (NSW Educational Testing Centre, 2000a, p. 9.)

Sam measured the temperature using this thermometer.

Julie measured the same temperature using a different thermometer like the one below. Which picture shows this temperature?
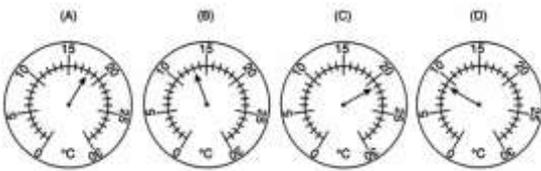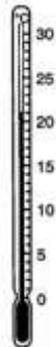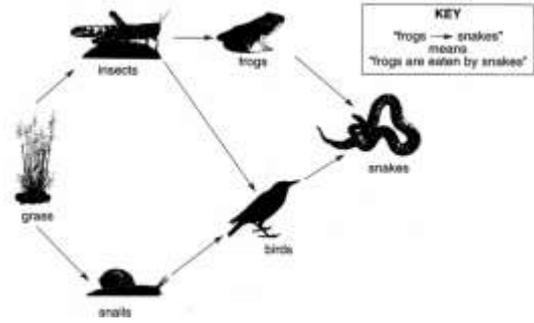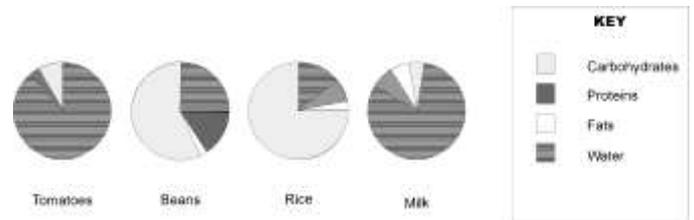

Answer
☐ A   ☐ B   ☐ C   ☐ D

Item 11, Miscellaneous (NSW Educational Testing Centre, 2000b, p. 3.)

The graphs below show the proportion of carbohydrates, proteins, fats and water in some foods.

Which food has the highest proportion of carbohydrates?

Answer
☐ tomatoes   ☐ beans
☐ rice   ☐ milk

Item 12, Miscellaneous (Adapted from NSW Educational Testing Centre, 1999, p. 2.)