Exploring some complexities of Mathematical Literacy assessment tasks

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Abstract
The introduction of Mathematical Literacy as a compulsory subject for those learners in the Further Education and Training band who are not studying the subject Mathematics has been an innovative step in trying to build up mathematical literacy skills in the country. The main emphasis has been to help learners make informed decisions in real life by using mathematical skills. However there is a mismatch between the purported aims of ML and the emphasis of many Mathematical Literacy assessment tasks in examinations. In this paper I draw attention to specific aspects of complexity relating to engagement with ML assessment tasks by looking at the demands of the two intertwining domains of ML- the mathematics and contextual domains. I argue that the contextual domain has context-specific resources which need to be recognised and used together with mathematics resources to solve ML assessment tasks.

Key words: Mathematical Literacy; assessment; context-specific resources; taxonomy

1. INTRODUCTION

In South Africa, authorities are most concerned that our past education has resulted in very low levels of numeracy in our adult population. International studies show that South African learners perform close to the bottom in mathematical literacy test items when compared to other counties (Howie, 2001; 2004; Soudien, 2007). In response to this widespread problem, one of the interventions from the Department of Education was to introduce the subject Mathematical Literacy (ML) as a fundamental subject in the Further Education and Training (FET) band in order to help develop numeracy skills among South African citizens. In common with many authors, Mathematical Literacy (ML) refers to the school subject while mathematical literacy is a competence. ML seeks to produce learners who are participating citizens, contributing workers and self-managing people (DoE, 2003). Its purpose is not for learners to do more mathematics, but more application and to use mathematics to make sense of the world.

The definition of ML by the DoE (2003, p. 9) is as follows;

> Mathematical literacy provides learners with an awareness and understanding of the role that mathematics plays in the modern world. Mathematical Literacy is a subject driven by life-related applications of mathematics. It enables learners to develop the ability and confidence to think numerically and spatially in order to interpret and critically analyse everyday solutions and to solve problems.

Curriculum documents emphasise that in ML, context and content should be inextricably intertwined in any teaching and learning situation:

> When teaching and assessing Mathematical Literacy, teachers should avoid teaching and assessing content in the absence of context. At the same time teachers must also concentrate on identifying and extracting from the context the underlying mathematics or 'content'. (DoE, 2007, p. 7)

These extracts emphasise that the nature of Mathematical Literacy (ML) is such that it entails working in both a contextual domain and a mathematics domain. Most(ML) assessment items require learners to negotiate between the two domains without falling into the trap of justifying her/his responses on her everyday knowledge and experiences — that is, successful ML students have learnt how to ignore the third domain, that of everyday experiences.

In this paper, I present some complexities related to accessing and using contextual resources when solving ML assessment tasks in South Africa. My perspective is that ML is a subject that entails the use of mathematical tools and resources together with those from the contextual domain, in order to solve mathematical problems which are interpreted in the context.

I argue that the context has specific resources which need to be recognised and used in specific ways which may be different from mathematics resources. Drawing on previous studies, I will outline in this paper some of the complexities of recognising and using these resources. The research question I will try to address is: What are the contextual resources present in ML assessment items? I conclude by arguing that the ML assessment taxonomy which privileges mathematical discourse may lead to a situation where ML assessment tasks are superficially made to resemble real life context, but which have unchallenging contextual resources. However this approach will not lead to a fulfilment of the ML mandate of enabling learners to make informed decisions in life.

2. RESOURCES OF THE CONTEXTUAL DOMAIN

There are some characteristics of contexts that seem to influence the success of learners in the assessment items designed around contexts. One of the conditions for success in these assessment tasks, is access to *context-specific resources* that need to be utilised in order to solve the task. By *context-specific resources* I refer to the specialised rules, language and terminology, signifiers or objects, visual mediators and reasoning that are utilised by people who interact within these contexts. Thus some of the demands of contextualised assessment relate to the identification and use of these contextual resources. In this section I will first outline what I mean by each of the terms (context-specific terminology, context-specific rules; context-specific reasoning; context-specific visual mediators and context-specific objects and signifiers) and then present some examples to exemplify their meaning. Thereafter I will discuss how the presentation of crucial information relating to these resources sometimes hamper learners access to these resources.

2.1. Context-specific terminology

Context–specific terminology refers to phrases which hold a particular meaning within the context. Below are five examples taken from scenarios of ML tasks are:

'*200 free kilometers per day*' is a phrase used in brochures about car hire rates. It refers to the situation where the contract allows you to drive up to 200 km a day without incurring additional charges. If a client hires a car for a certain number of days and drives more than 200 × number of days in total, then there is a specific charge per km that must be paid by the client. I observed a group of teachers working on this task who struggled to interpret this phrase and were unable to calculate the exact amount due. They got caught up trying to figure out when this stipulation was valid.

'*base occupancy'* is phrase used in brochures about accommodation agencies. It refers to the number of people that can stay in the room/chalet without incurring additional fees. For example if a client books a cottage with a base occupancy of 2, it means that the quoted cost is based on the assumption that two people will stay there.

'tariffs for an additional person' is a charge usually quoted together with the preceding one and refers to the amount that must be paid per person if the base occupancy is exceeded. A study done by Khan (2009) on learners who attempted the assessment item, revealed that none of the learners in the class arrived at the expected answer. Part of the task involved calculating the cost of accommodation for 18 boys (12 years old) who were going to stay in the safari tents. Learners ignored the base occupancy information and just calculated the number of tents that would be needed by dividing the total number of children by the maximum number per tent (provided in the table). Many learners stopped at that step without going any further. One student then multiplied the result by the tariff for an additional child-charge, provided in the last column of the table, showing that she did not know what the phrase meant. When interviewed she expressed frustration with the overload of language and information that she could not understand, saying "don't say, don't give us the passage … just give us the equations only".

'5% on the value above R500 000' is a phrase used in the rule for calculation of the transfer duty of a house costing between R500 001 and R1000000. In a study by Bansilal, Mkhwanazi and Mahlabela (forthcoming) it was found that some students misinterpreted this and took it to mean 5% of the total cost instead of 5% of the amount by which the total cost exceeded R500000.

'win by a margin of 2 or more…' is a phrase used in the context of soccer goals. It refers to the situation where the difference between the goals scored by the winning and the losing teams is 2 or more than 2. In a study by Bansilal and Debba (forthcoming) it was shown that some learners were unable to answer certain questions because they did not understand the meaning of this phrase.

2.2. **Context–specific rules**

Context–specific rules, are bound to the context and need to be interpreted by the learner. These rules are used for calculations in the context. Below are two examples, the first is taken from Bansilal et al (forthcoming) while the second is taken from KZNDoE (2009).

Figure 1 Calculation of transfer duty of a house:

The formula that is used to calculate the transfer duty, payable by a new home owner, is as follows:

- For a purchase price of R0-R500000, the transfer duty is 0%.
- For a purchase price of R500001 to R1000000, the transfer duty is 5% on the value above R500000.
- For a purchase price of R 1000001 and above, the transfer duty is R25 000 + 8% of the value above R1 000000.

This is a rule that must be followed in order to calculate how much of transfer duty is payable by a new house owner.

Figure 2 Calculation of points for teams playing in the FIFA world cup

FIFA awards 3 points for a **Win**, 1 point for a **Draw** and no point for a **Lose**.

The log table shown in TABLE 3 below is based on the following results.

Match 1: Spain 3 , South Africa 3
Match 2: South Korea 2 , USA 2
Match 3: South Africa 1, USA 1
Match 4: Spain 4 , South Korea 2

TABLE 3: Log Table

COUNTRY	WIN	LOSE	DRAW	POINTS
Spain	1	0	1	4
South Africa	0	0	2	**D**
USA	0	0	2	2
South Korea	0	1	1	**E**

The FIFA calculation formula is used to calculate the number of points achieved by the different soccer teams.
It is often the case, that the context rule is given in verbal form, like the FIFA points system. However some context-specific rules may require learners to translate the rules into mathematical language before solving the problems, for example the rule in Fig 1 may require one to write the subtraction and the percentage calculation using mathematical symbols.

2.3. **Context-specific reasoning**

Context-specific reasoning is the reasoning, arguments or assumptions made about issues in the context. People who work with or understand the context in real life are able to make judgements or decisions about the information that is presented by engaging in the particular form of reasoning that is accepted as legitimate in the context. Implicit assumptions about the context are often taken for granted by the task designer. For example, for the pizza problem (below), learners need to understand that a pizza can have a thick base or a thin base, and that toppings are then chosen:

Figure 3 Pizza Problem

Pizza Task

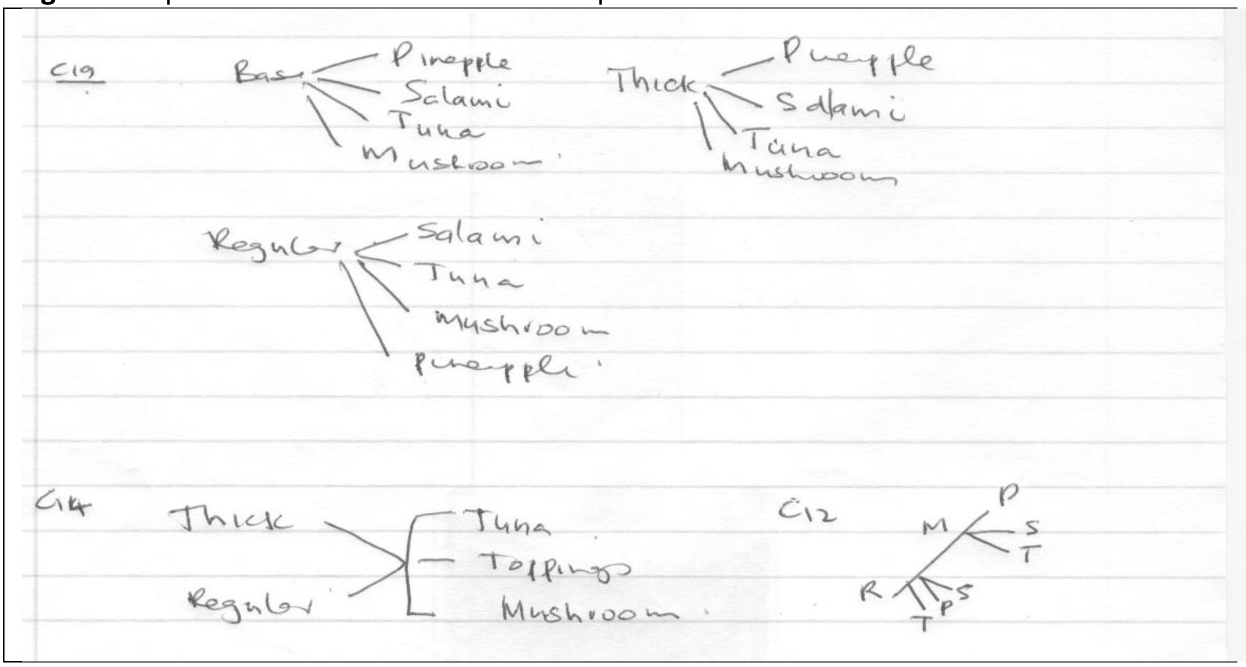
At a restaurant at the Waterfront in Cape Town, tourists have a choice of different pizzas:

BASE	*TOPPINGS*
Thick	*Pineapple*
Regular	*Salami*
	Tuna
	Mushroom

If a tourist buys a pizza with three toppings, how many combinations are possible? (Use any systematic counting method that you have learnt.)

The question above requires the knowledge that a pizza is a meal which consists of a base which could be thick or regular and consisting of toppings which were placed on the base. This would help them understand that they needed to choose between the bases firstly and then make a second choice of three toppings from the four that were available. Without understanding what a pizza was, a learner would be unable to understand the question. A study (Bansilal, 2008) revealed that some learners were disadvantaged because they did not understand what a pizza was. These learners were unable to move on to working out the number of possible combinations (using mathematical tools) because their idea of a pizza was not clear. For example one learner thought that the pizza was made of 4 quarters, with one quarter reserved for each topping. In his scheme, there would only be two types of pizza- one with a thick base and the other with a regular base. Examples of learners' work showing a misunderstanding of what a pizza was, is shown below.

Figure 4 Reproductions of learners' work on pizza task

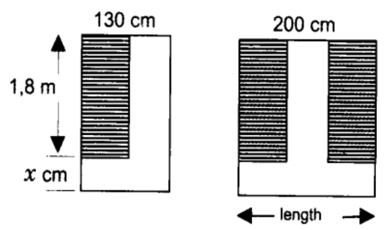


The above diagrams have been reproduced and manipulated so that they fit into the page, taken from Bansilal (2008)

Another example of context-specific reasoning demanding implicit assumptions is provided by the Prison Cell task below:

Figure 5 Robben Island Prison Task

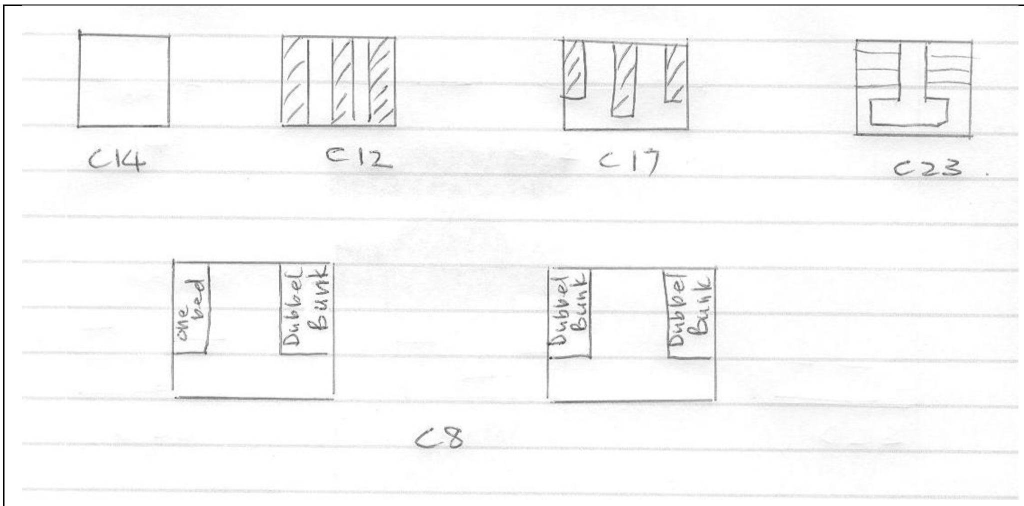
The main tourist attraction on Robben Island is Section B of the prison, where Nelson Mandela spent 18 years of his 27-year imprisonment.
There were dormitories accommodating 60 to 70 prisoners sleeping on sisal mats on the stone floor. There were also cells with very narrow beds, as shown below. This investigation will give you a sense of how the prison warders planned to fill the cells with prisoners.
The following diagrams represent the arrangement of one bed or two beds in cells. The length of a bed is 1,8m and the width is 70 cm. There is a distance of 60 cm between two beds and x cm between the bed and the wall, as indicated in the diagram.



Based on the diagrams for a one-bed and a two-bed cell, draw your own diagrams to show the size of the two cells that would accommodate three beds and four beds. Indicate the dimensions in your diagrams.

Some examples of students work in response to the above question appear below taken from Bansilal (2008).

Figure 6 Reproduction of learners drawings of prison cells with beds



These diagrams have been reproduced to summarise the misinterpretation about the kinds of arrangements of beds that were permissible in the task. C12 drew beds from end to end. C17 drew three beds of different sizes and C8 used his everyday knowledge of prison cells to draw double bunk beds. These learners did not recognise the assumptions about the design and arrangements of the beds as conveyed in the description and initial diagrams provided in the task.

A third example of *context-specific reasoning* in the context of international or national sports competitions (such as in an F1 championship) is the process of responding to the question, “What are the chances of a driver leading the championship by 8 points, winning the championship with only one race to go?” There would be various possibilities, involving the competitors as well, that must be considered: The driver has to win the race to secure 10 points and hence win the championship, or the driver can complete the race without being placed provided that the second driver does not complete the race or is unplaced, or the driver can be the runner up securing 8 points and the second driver being awarded 10 points for a win. This would result in a tie for the championship. The reasoning that is used is based on a consideration of the possible outcomes that are recognised in the awarding of points, and is specific to the context. It differs from everyday reasoning where an argument is based on an opinion or a consideration of other realistic issues.

Similarly in making judgments about the possibility of a particular horse winning a race, bookmakers analyse the weights, the horse’s history, the horse’s form, the trainers’ history, the owner’s history, the jockey’s history, the jockey’s weight, the race type amongst other factors before they make predictions about the horse’s likelihood of winning a particular race. Again this kind of reasoning is different from mathematical reasoning or everyday reasoning, it relies on specialist knowledge which may be available in the public domain.

2.4. Context-specific signifiers and objects

Context-specific signifiers and objects refer to the signifiers or objects used in the context to convey specific information, and which has a meaning that is bounded by the parameters of the context. I present two examples here taken from ML assessment tasks.

In the context of inflation, the figures reported in the media each month as the “monthly inflation rate” figures for the CPI need some unpacking before they can be understood. CPI (Consumer Price Index) is the average (weighted mean) cost of the “shopping basket” of goods and services for a typical South African household. The total South African basket consists of about 1500 different consumer goods and services, and is based on many processes before average cost of the “basket” is worked out. Price movements on the goods comprising the basket are measured and the CPI is compiled using the price movements per product and their relative weight in the basket. (Lehohla, 2011). The process can be represented simplistically as follows: If P_1 represents the current average price level and P_0 the price level a year ago, the rate of inflation during the past year is measured by

(I_1) = $inflation\ rate = \frac{P_1 - P_0}{P_0} \times 100\%$. ……………………………………(1)

Thus a reported monthly inflation rate figure of 4.2 % (June 2011), needs to be unpacked to be understood. Taking 4.2% as I_1, as the monthly inflation rate for June 2011, this means that P_0 and P_1 represents the price levels in June 2010 and June 2011 respectively. Usually inflation rate figures are reported on a monthly basis. The *monthly inflation rate* refers to the year–on–year rate calculated on a monthly basis and does not represent a month-on month rate.

A second example of a context-specific signifier is provided by a task on infant mortality rates used in the 2008 Grade 12 KZN ML trial examination paper. In the task a table with the statistics of infant mortality between 2004 and 2008 due to different illness was presented.

Table 1 Statistics of infant Mortality Rates taken from KZNDoE (2009)

Year	Polio	Measles	HIV-Aids	Hep. B
2004	2	1	5	0,8
2006	1,8	1,2	3	0,9
2008	1	1,1	3	1

The information identifying the meaning of infant mortality rate appeared in a block at the beginning of a question, amongst other details:

Figure 7 Meaning of infant mortality rate

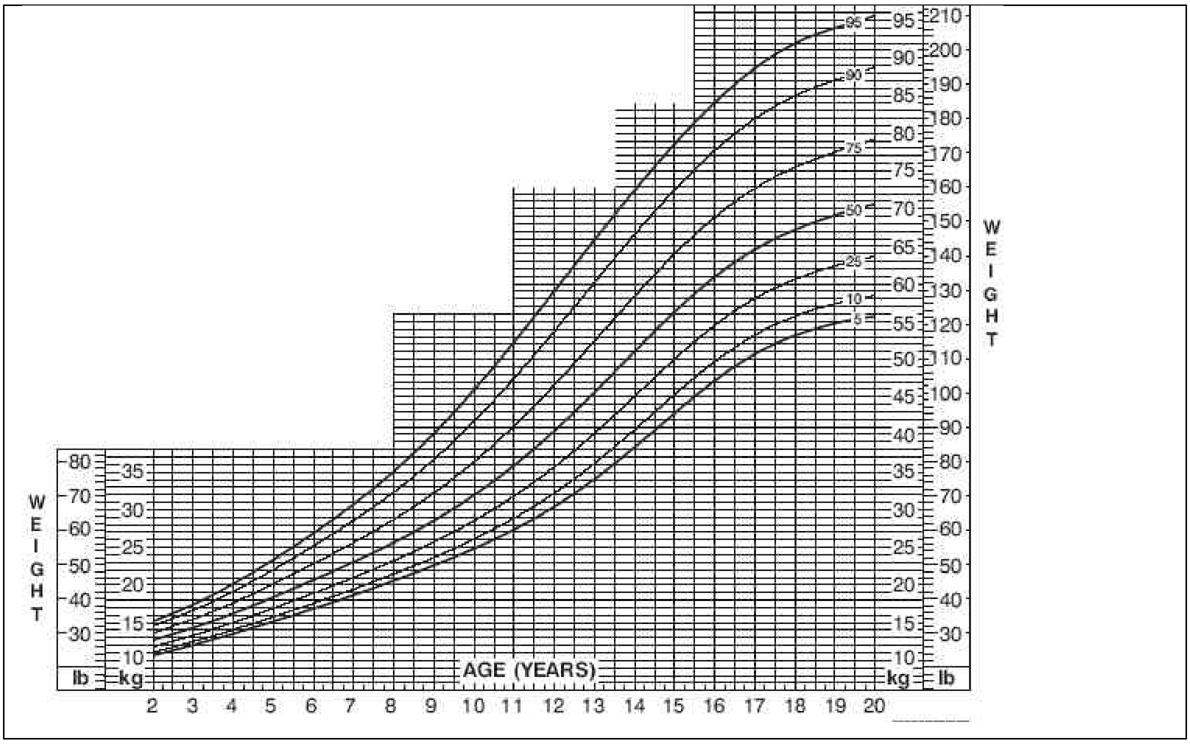
Between 2004 and 2008 research was conducted to assist the government in identifying causes of high infant mortality rate (i.e the number of infant deaths during the first year of life per thousand live births). …[other details included]

This meaning of infant mortality rate is quite complex. In order to answer the questions, learners needed to understand that, for example, the numeral 2 (2004, Polio) from Table 1 refers to the fact that 2 children out of every 1000 children that were born (excluding still-born) died of polio within their first year.

2.5. **Context-specific visual mediators**

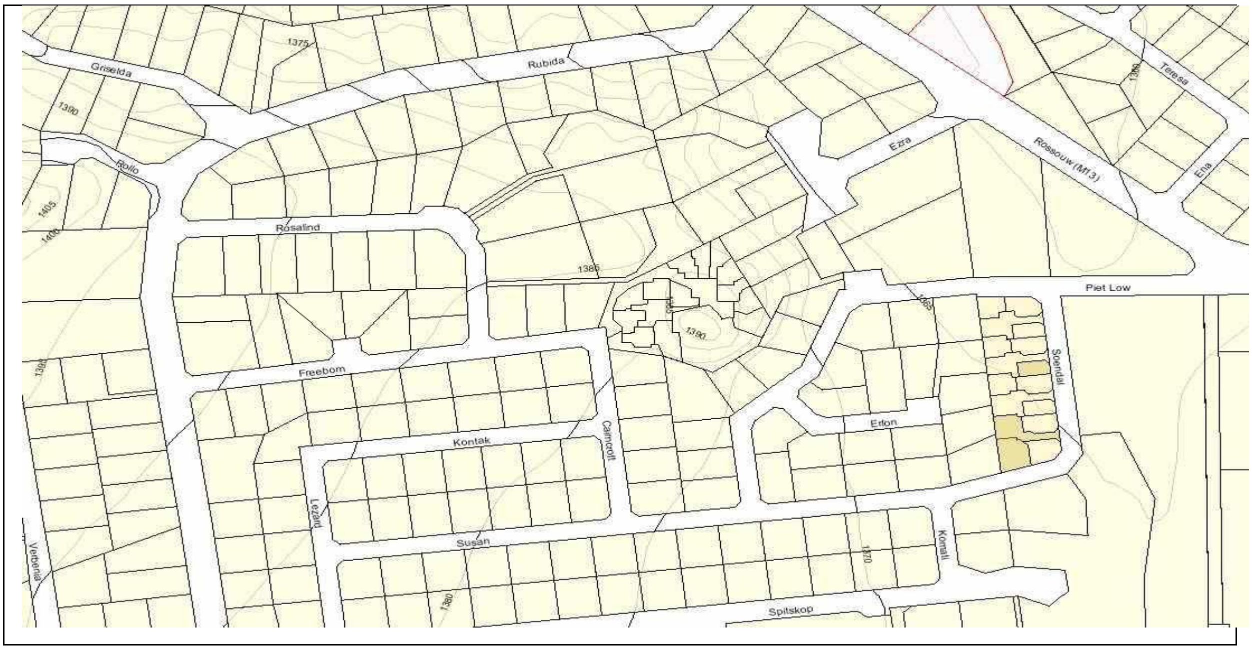
Context-specific visual mediators. These refer to visual information presented in diagrammatic, graphical or other form. For example, graphs showing the growth of babies, e,g the following chart Boys: weight-for-age percentiles (DoE, 2008, p.32).

Figure 8 Boys weight for age chart (DoE, 2008, p.32)



Another example of a context-specific visual mediator is the map of a district used in an ML task based on Shape and Space concepts using newspaper delivery routes as a context. This map is reproduced below in Figure 9.

Figure 9 Map of neighbourhood used in task on newspaper delivery routes



2.6. **Crucial information**

Crucial information refers to information and details about these context-specific resources, which are provided by the task designer in the task itself, without which the task cannot be solved (Bansilal & Wallace, 2008). An ML assessment task can usually be divided into three parts as described by Anderson (2005). The three major components are the introductory material, the stem, and the response. The **introductory material** gives the background to the question or some information on which the question is based. It may be some written text, a diagram or a real object. This forms the scenario in the mathematics literacy paper. The **stem** is the actual task that the learner have to complete. It may be a question to answer, an incomplete sentence that they have to complete, or an instruction that they have to carry out. The **response** is what the learners have to do to answer the question.

The crucial information is usually provided in the introductory material and learners access to the task is dependent on their ability to recognize, extract and use the crucial information. The problem of non-recognition of crucial information may occur because of an overload of unnecessary context information (Bansilal & Wallace, 2008) and sometimes because of too much of text that needs to be read before you get to the crux of the issue.

At other times learners may miss the crucial information because it appears too far away from the stem of the question. For example in a study of Grade 12 learners engagement with tasks from the MLTrial examination (Debba, forthcoming: p.59) found that many learners missed crucial information in two questions when the information appeared in the introductory material but was only needed much later, in one case, 8 questions later:

This question required learners to calculate the number of babies who survived their first birthday. The scenario, presented at the beginning of the question (Question 4) contained the crucial information that would allow them to interpret a mortality rate of 8,8 as 8,8 deaths per 1000 births. There were then 7 sub–questions which followed, none of which required any crucial information provided in the scenario. Then Q4.2.1 appeared as the eighth sub–question, and the only one which needed that crucial information. In Q4.2.1, most learners had a problem was with the interpretation of the figures in the table (see Table 1) This information was crucial and needed to be readily available so that the learners could engage with the meaning of the figures. By placing the information so far away, they missed it- thus reducing the validity of the assessment question. None of the 73 learners [of the sample] were able to appropriate that crucial information in their solution. Below is Debba's reporting of interviews with two learners.

> Respondent 2 said she missed the crucial information because she *"didn't read the block".* When directed to the part where the information was given, Respondent 4 said that it would have been better if the information was given close to the question so it could be seen. When directed to the scenario at the beginning respondent 5 then realized that the values represented deaths per every 1000 live births and suggested that:
>
> > *"They should have put the scenario just above the question so we wouldn't have missed it out. They put the scenario above the different set of questions on the scenario and put another table they could have put it under each and said refer to A or B that would have been better."*

In this section, using data from previous studies I have described particular practices associated with particular contexts. Before a learner can use any mathematical tools to make interpretations, s/he needs to first understand these practices. When the crucial information presenting the contextual resources is obscured, learners' engagement with the tasks will be hampered.

3. TOOLS IN THE MATHEMATICS DOMAIN

Tools and resources from the mathematics domain are crucial for engagement with ML assessment tasks. I will use Sfard's (2008) theory about discourses in mathematics to illuminate some issues about engagement in the mathematics domain.

3.1. Mathematics Domain

Brodie & Berger (2010) explain using Sfard's (2008) theory, that flexible movement between discourses of domains is key to mathematical expertise and novices struggle the most at this point. Discourses are characterised by the constructs of objects and signifiers, visual mediators, routines and narratives (which do not exist in the mind but in the discourse) (Sfard, 2007). A narrative is any "text, spoken or written that is framed as a description of objects or of relations between objects or activities with or by objects and that is subject to endorsement or rejection, that is, to being labelled true or false" (Sfard, 2007, p.572).
According to Sfard (2007, p.571) "visual mediators are means with which participants of discourses identify the object of their talk and coordinate their communication". These include: formulae, graphs, drawings and diagrams. Routines are "well defined repetitive patterns in interlocuters' actions, characteristic of a given discourse" (2007, p.572). Routines are not merely mathematical procedures, but include these. Participation in the discourse is facilitated when interlocuters are able to consider both how and when routines are generated. The process of participating in a Mathematics discourse, involves creating narratives about objects in the new discourse. As we communicate with more experienced discursants, we begin to see how to use the elements of the new discourse appropriately.

ML learners working on assessment tasks can be viewed as participating in practices involving formulating contextual and mathematics relationships from text. Success at the ML test items is often dependant on students' ability to identify the contextual resources located in the contextual domain, and to use them in the discourse of mathematics. Using the language of Sfard (2008), the objects and signifiers characterising the context, have to be used in conjunction with objects, visual mediators and routines and narratives located in the discourse of mathematics. The students need to identify the appropriate mathematics routines and narratives which would allow the contextual objects to be interpreted and understood in the mathematical discourse. This is evident from the description of the levels of assessment in the ML assessment taxonomy where progression is framed in terms of mathematical procedures.
Mathematics signifiers, visual mediators and routines are often different from contextual ones because they serve different purposes, and are used in different ways. They may be similar. For ML assessments, it is mathematics narratives that are privileged because of the emphasis of the subject on life-related applications of mathematics. However, learners use contextual signifiers, visual mediators, and rules to create mathematically endorsed

narratives. In terms of reasoning they are sometimes required to use both contextual and mathematical reasoning to justify decisions.

4. CONCLUDING REMARKS

Many South African researchers have paid attention recently to understanding levels of complexity in ML tasks. Assessment at school level in ML is guided by the ML assessment taxonomy (DoE, 2008, p 27-28) which specifies 4 levels in the hierarchy: Knowing, Applying routine procedures in familiar contexts, Applying multi-step procedures in a variety of contexts and Reasoning and reflection. Marc North (2010), in his analysis of the 2008 Grade 12 Mathematical Literacy Examination paper, found that it did not adhere to the stipulations of DoE assessment documents in terms of content coverage and cognitive difficulty. In terms of content coverage, LO1 (Numbers and Operations) were over represented while LO2 (Functional Relationships) and LO3 (Shape, Space and Measure) were under represented. Assessment of several topics such as inflations, taxation, quartiles, percentiles, and graphs with negative axes, were completely omitted. The unbalanced distribution of marks according to the taxonomy levels, where a low percentage of marks were allocated to Reasoning and Reflecting and a high percentage of marks allocated to Routine Procedures, made the examination assessment cognitively less demanding, and hence contributed to a false impression of the high pass rate in the subject in 2008.

Venkat, Graven, Lampen and Nalube (2009) have criticised the taxonomy for a number of reasons, one of which is that “combining content (in terms of facts and procedures) and context oriented complexity within a single hierarchy appears to suggest that both these aspects become more complex together” which is in contrast to the case of the UK subject Functional Mathematics where the categories suggest that these two aspects can vary independently of each other (Venkat et al., 2009, p.46). A further critique is that the “taxonomy appears … to separate the ‘doing’ of ML from the ‘reasoning’ required for ML” (Ibid, p.50)

A blind following of the assessment taxonomy which privileges mathematical discourse may result in ML assessment tasks being made to superficially resemble real life situations. A reduction of the “realness” reduces the value of the task as a vehicle to build learners’ awareness of the power of making informed decisions based on an engagement with the available information. In order to help learners make informed decisions, they need to be exposed to assumptions and particular ways in which decisions are taken in various contexts. This demands firstly understanding the contextual rules and assumptions underpinning certain issues and secondly a higher engagement with these context-specific resources that will allow them to compare, reason, and make decisions about various scenarios by using mathematical tools and resources. When task designers neglect the way in which the crucial information is presented, learner’s progress is limited because they cannot proceed to the task of mathematisation. Some tasks bypass this step by using contexts as a Macguffin. William (1997) claims that relevance is a Macguffin — a metaphor used by Alfred Hitchcock to describe a plot device primarily introduced to motivate action in a film and to which relatively little attention is paid. In mathematics classrooms, a Macguffin is a mechanism to motivate learners to convince them that the activities they are given are somehow of the real world even though they do not appear to be connected to it (William, 1997).

In his analysis of the 2008 Grade 12 Mathematical Literacy examinations, North (2010) found many of the contexts used were "pseudo-contexts" (p12). They were contexts that were either artificially constructed, inappropriate to the mathematics being explored in that context, or refocused to draw attention to specific mathematical concepts (p12) and away from the real-life. Pseudo-contextualisation, he argues, inhibits "mathematisation" since the contexts are inappropriate, unrealistic or artificial.

I argue that the tasks which are most useful are the one whose contextual resources may be complex to unpack and may require sustained engagement. A necessary condition for the validity of such contexualised tasks is the clear, unambiguous, minimal and accessible presentation of the crucial information. Text-based examination type assessments are not the most useful vehicle to develop such skills because of the baggage that is attached to acquiring high pass rates. This drive results in pressure to design assessments that have accessible information with unchallenging contextual resources. Some consequences of such a path are: a reduction of tasks to step-by-step instructions; judicious placement of formulae close to the question, thus overriding any need for a modelling exercise; relegating reasoning questions to follow specific calculation exercises. All these characteristics are currently a common feature of the Grade 12 national ML examinations.

Some of the real life artifacts and discussions about them are very valuable opportunities for informed citizenship, and should not be abandoned just because they pose a headache in designing fair assessments around them. The whole philosophy and guiding principles behind the introduction of ML are too important to be reduced to a set of examination questions that everybody has familiarized themselves with and learnt to pass by learning to "read" the questions, or even just reducing engagement with contexts to asking learners to extract data from the context and substitute it into readily available formulae.

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