Context in mathematics examination questions

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January 2013

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1.1 Definitions of context

Several authors argue that the term context is particularly difficult to define for mathematics (Berry, Maull, Johnson and Monaghan, 1999; Little and Jones, 2007; Vappula and Clausen-May, 2006). Berry et al. (1999) believe that no definition can be found and consider that it is more useful to think about routine and non-routine questions. Rather than there being definitions of context, there are taxonomies of context.

1.2 Taxonomies of context

There are several taxonomies (categories or classification systems) which describe context. Some taxonomies were developed for pre-16 mathematics (Ahmed and Pollitt, 2007; Mevarech and Stern, 1997; Vappula and Clausen-May, 2006; Watanabe and Ischinger, 2009) while other taxonomies relate to learners aged 17 or 18 (Debba, 2011; Little and Jones, 2007). The taxonomies are summarised below to further describe context and introduce terms used in the report.

Mevarech and Stern (1997) refer to sparse versus real contexts of questions about linear graphs. They do not give definitions. However, their work implies that real contexts are everyday contexts, and sparse contexts are more school-orientated contexts and potentially abstracted from everyday life.

Vappula and Clausen-May (2006) argue that contextualised questions are those that are set out as stories about real-life events, although contextualisation does not require the re-telling of a story. Context can be a pictorial or a verbal model.

Watanabe and Ischinger (2009) categorise contexts as follows:
- *Personal contexts* – of direct personal relevance to learners.
- *Educational and occupational contexts* – scenarios that learners might confront while at school (including somewhat artificial problems) or problems that would be met in a workplace.
- *Public contexts* – situations experienced in everyday life such as something read in a newspaper.
- *Scientific contexts* – occur when the question is in a science context such as presenting experimental data.

Debba (2011) used work by du Feu (2001) to derive question types, according to the characteristics of their context.

The categories were:

- *Context-Free* – simple equations and one-step arithmetic with no context.
- *Real Contexts* – real problems which reference any named individual(s), institution(s), artifact(s), organism(s) or product(s). These contexts are mainly statistical in nature where the data used is quoted and the source acknowledged.
- *Cleaned Contexts* – real-life contexts simplified to make the question accessible to the learner or suitable for the time constraints of an examination.
- *Parables* – fictitious contexts attributed to an anonymous person/company/organism. Their function is to make some point, for example, to teach or test some mathematics.
- *Contrived Contexts* – invented to fit a particular mathematical point, irrespective of how appropriate these situations are to real life.

Some authors also classify questions according to the purpose of the context. Vappula and Clausen-May (2006) argue there are two purposes for contexts. The first purpose is getting the story across rather than supporting the learner with the mathematics. The second purpose is to provide a model for the learner to think with.

Watanabe and Ischinger (2009) also provide a classification system which relates to the purpose of the context:

- *Zero order* – nothing about the context is needed to solve the problem.
- *First order* – the context is relevant and needed to solve the problem and judge the answer.
- *Second order* – there is a need "to move backwards and forwards between the mathematical problem and its context in order to solve the problem or to reflect on the answer within the context to judge the correctness of the answer" (Watanabe and Ischinger, 2009, p. 31).

There are similarities between the taxonomies structured according to the purpose of the context. Zero order contexts (Watanabe and Ischinger, 2009) are similar to contexts intended to get the story across and not to support the mathematics (Vappula and Clausen-May, 2006). First and second order contexts (Watanabe and Ischinger, 2009) are similar to contexts that provide a model for the learner to think with (Vappula and Clausen-May, 2006).

The taxonomies summarised above are descriptive or are structured according to the purpose of contexts. There are two further taxonomies by Little and Jones (2007) and Ahmed and Pollitt (2007) which can be used to evaluate the quality of the context.

Ahmed and Pollitt (2007) classify questions according to whether they are focused or unfocused. A focused question addresses the aspects of the context that will be most salient in real life for the learners. Unfocused questions do not address the aspect of the context that will be most salient in real life for learners. A more focused context, then, will help to activate relevant concepts, rather than interfering with comprehension and reasoning.

Little and Jones (2007) and Little (2010) refer to various characteristics of contexts:

- *Accessibility* – the familiarity and comprehensibility of the context, including the comprehensibility of the language and the explicitness of the match between context and mathematical model
- *Realistic* – the fit of the mathematical model to students' perceptions of real life:
  - *Natural contexts* match reality
  - *Synthetic contexts* configure reality to match the mathematics and can reify abstract mathematical ideas. Synthetic contexts have also been described as mathematics looking for somewhere to happen (Wiliam, 1997).
- *Authentic* – how relevant and useful the solution of the question is to the context.

While there are several taxonomies of context, they are broadly similar. For the purpose of this review context is taken to include all of the taxonomies discussed above.

It is important to note that there is a distinction between context and situation, particularly in the research drawing from constructivism or theories of situated learning / cognition (Boaler, 1993a, 1998; Imm and Stylianou, 2012). Context is the account that surrounds a mathematics problem / task / skill in teaching / learning / assessing, whereas the environment or situation is the physical and social surroundings of using mathematics, teaching and assessing. For instance, if a teacher asks the class to solve the following problems on a worksheet:

2+2=____

John has two sweets and Mohamed has two sweets so how many sweets are there in total?

The first problem is context free and the second has the context of children with sweets. The situation is identical for both problems: a teacher conducting a low-stakes assessment in the classroom.

1.3   Methods used to research the effects of context

Researchers have used a variety of methods (often in combination) to investigate context. They have:

- Analysed examination questions and mark schemes (Debba, 2011; Little, 2010; O'Sullivan, Breen and O'Shea, 2012; Vurayai, 2012).
- Analysed learners' responses to examination questions, eg calculating facility values or analysing the responses (Angoff, 1989; Debba, 2011; Fisher-Hoch, Hughes and Bramley, 1997; Watanabe and Ischinger, 2009).
- Observed and interviewed learners and staff in classes and schools (Boaler, 1993a, 1998; Imm and Stylianou, 2012; Vurayai, 2012).
- Administered questions with particular features (such as exam questions or adapted exam questions), analysed the responses and compared the responses to different questions (Ahmed and Pollitt, 2000, 2007; Boaler, 1993a, 1998; Crisp, Sweiry, Ahmed and Pollitt, 2008; Fisher-Hoch et al, 1997; Little, 2010; Little and Jones, 2010; Schroeder, Copeland and Bies-Hernandez, 2012; Song, 2011; Vappula and Clausen-May, 2006).
- Experimented with different conditions, eg manipulations of questions (Khateeb, 2008; Mevarech and Stern, 1997). (Some of the work in the previous bullet point was conducted as experiments.)

- Interviewed learners about their experience of attempting a question (Ahmed and Pollitt, 2007; Debba, 2011; Dolan, Goodman, Strain-Seymour, Adams and Sethuraman, 2011).
- Recorded learners thinking aloud as they attempted questions (Dolan et al., 2011). The verbal reports are known as think aloud verbal protocols. Cognitive labs are a combination of think aloud verbal protocols and interviews about learners' experience of responding to questions (Dolan et al, 2011).
- Recorded learners attempting a question, showed the learners the recording and interviewed them about their experience. Responses are analysed to understand how the learners are understanding the question and trying to answer it (Ahmed and Pollitt, 2000). This is known as stimulated recall.
- Administered questionnaires to learners about their experience of the examination questions and analysed the responses (Little, 2010; Song, 2011; Vurayai, 2012).
- Asked learners for a written explanation of how other learners attempted the question (Clausen-May, 2006).

2 Question 1 – What are the advantages and disadvantages of testing mathematics in context?

There are several advantages and disadvantages to testing mathematics in context. The literature indicates that advantages and disadvantages are often associated with particular type(s) of context and this is reflected in the information that follows. The advantages and disadvantages are organised by assessment topics such as the construct and the question answering process.

2.1 Advantages

2.1.1 Construct

- Context was used to test whether learners can solve problems in new situations (Ahmed and Pollitt, 2007).
- Focused questions generally allowed learners to achieve more marks without changing the mathematics demand (Ahmed and Pollitt, 2007).
- Focused questions generally avoided construct irrelevant variance and invalidity (Ahmed and Pollitt, 2007).

2.1.2 Natural and synthetic contexts

- Computer-based testing helped enable contextualised questions to better mimic the real world (Dolan et al, 2011).
- Synthetic contexts were not necessarily bad; they were artificial models of a context which learners could be asked to evaluate (Little, 2010). Learners could be asked to discuss and compare models and hence appreciate the relationship between reality and mathematical models (Little, 2010).

2.1.3 Question answering process

- Focused questions generally provoked fewer misunderstandings than unfocused context (Ahmed and Pollitt, 2007).
- Context helped candidates answer a question when everyday reasoning and the correct method of answering the question coincided (Debba, 2011). For example, a football fan answered a question about teams and points in a league system. Their experience of the game and the point system helped them to identify the crucial information needed to solve the question accurately (Debba, 2011).
- Context did not hinder any more learners than did abstract presentations (Vappula and Clausen-May, 2006).

2.1.4 Performance

- Story contexts did not hinder learner performance (Vappula and Clausen-May, 2006).
- The level of real-life relevance that learners attributed to the context did not relate to performance (Debba, 2011).

- Context in data-handling questions provided meaning for the questions; context-free data-handling questions reduced performances as the questions were devoid of meaning (Fisher-Hoch et al, 1997).
- Context was not a major factor in determining difficulty. Competencies, content, item format (complex multiple choice, multiple choice, short answer, multiple short answer and extended response) and word count of an item were all better predictors of difficulty than context was (Watanabe and Ischinger, 2009).

2.1.5 Question answering process and performance

- Pictorial analogies provided models to think with and may have boosted performance (Vappula and Clausen-May, 2006).
- Contexts which were unique to the question may have boosted comprehension and performance (Schroeder et al., 2012).
- Real-world contexts helped ease the difficulty of questions which can be solved by providing mental scaffolding for thinking within the context (Little, 2010). Context may have provided 'mental scaffolding' to help the learner to use context-specific heuristic strategies (Little and Jones, 2010).

2.1.6 Marking

- Context questions were designed which were unchallenging to mark and measured the intended abilities. This was achieved by listing possible solutions to a question and asking learners to choose the correct solution or provide figures from the solutions (Clausen-May, 2006).
- Real-world contexts did not jeopardise reliability (test, retest and marking consistency), contrary to speculation (Little, 2010).

2.1.7 Teaching and learning

- Real-world contexts helped reinforce the perception that mathematics was useful (Little and Jones, 2010).
- Boaler (1998) found that context in questions did not advantage learners who experienced either of the following approaches to teaching and learning:
  - Conducting projects with considerable independence until just before the GCSE examination, when learners started practising formalised exam questions
  - Working through the textbook, asking for help at each new exercise (a content-based scheme) and preparing for exams.

2.2 Disadvantages

2.2.1 Construct

- Examination questions (with and without context) required candidates to undertake pseudo modelling because real-world contexts were embryonic modelling problems (Little and Jones, 2010). Examinations cannot test aspects of the modelling cycle, such as discussing assumptions and refining and critical reading of longer arguments (Little, 2010).
- Contexts which were sufficiently open for learners to negotiate their own context and develop deep, meaningful understandings were too lengthy for an examination, although they could be used for projects / controlled assessment (Boaler, 1993b).

2.2.2 Natural and synthetic contexts

- It was hard to find real-life contexts in which school mathematics readily fitted (du Feu, 2001).
- Some learners thought contexts were unrepresentative of their real lives (many of these contexts represented adult life) (Debba, 2011).
- Some learners found a context relevant and others did not (Debba, 2011).
- Some learners saw real-world contexts as artificial (Little and Jones, 2010).

2.2.3 Question answering process

- Fictional and unfamiliar contexts were particularly likely to cause learners to omit the question because they mistakenly thought they did not know the subject content (Ahmed and Pollitt, 2000).
- The accessibility of questions was a function of the language used and the explicitness of the match between context and mathematical model (Little, 2010).
- Unfocused context provoked some misunderstanding of the questions (Ahmed and Pollitt, 2007).
- Unfocused contexts contained extra unintended demand which was a threat to validity (Ahmed and Pollitt, 2007).
- When faced with a context-free question part within a contextualised question, many learners failed to move their thinking out of the context and realise that the question part required a simple textbook answer (Ahmed and Pollitt, 2000).
- Context questions often required candidates to make unrealistic assumptions (Clausen-May, 2006).
- Contextualisation in division questions encouraged pupils to use informal or drawn methods (Vappula and Clausen-May, 2006).
- When content was unexpected for the subject (eg a question about economics costs in science) it prevented some learners understanding the question and exhibiting their knowledge and skills (Crisp et al, 2008).
- When contexts corresponded to real-world situations which learners knew something about, it sometimes caused them to be unsure about whether to answer in terms of the subject or everyday knowledge, and which would get them marks (Ahmed and Pollitt, 2000).
- Learners' choices of mathematics procedures were likely to be determined by the testing situation rather than by the context (Boaler, 1993b).
- Complex contexts, information-heavy contexts and diagrams containing a lot of irrelevant information could all produce errors (Debba, 2011).
- Question layout affected the learners' ability to find crucial information to answer the question (Debba, 2011).

2.2.4 Performance

- Unfocused contexts contained extra non-subject difficulty (construct irrelevant difficulty) which prevented learners from showing their skills and gaining marks. This construct irrelevant difficulty was a serious source of invalidity (Ahmed and Pollitt, 2007).

2.2.5 Question answering process and performance

- The mathematical content was one factor that determined whether a context served to enhance understanding and performance (Boaler, 1993b).
- Language used to describe contexts was sometimes a barrier to understanding the question requirements and this reduced performance, especially when there were low levels of literacy (Debba, 2011). Real-world contexts increased the word length of the questions (Little, 2010).
- Context triggered learners' schemas of everyday experience and reasoning, which they used to answer questions, and resulted in wrong answers (Ahmed and Pollitt, 2000; Debba, 2011). For instance, when asked to work out an ATM cash withdrawal fee based on the amount of money withdrawn, one learner's answer was influenced by their bank providing free ATM withdrawals (Debba, 2011).
- Unfamiliar contexts were a barrier to particular groups of learners understanding or comprehending the questions (Boaler, 1993b; Debba, 2011; Song, 2011; Vurayai, 2012). Therefore they had a lower chance of performing well (Boaler, 1993b; Debba, 2011; Song, 2011; Vurayai, 2012).
- Real-world contexts increased question difficulty by requiring candidates to understand and match the context to the appropriate model, unless they could be solved by thinking within the context (Little, 2010).
- Learners' experience influenced how they interpreted the context and answered the question (Debba, 2011). Learners had an individual understanding of the context, making the question difficult for some and easier for others (Boaler, 1993b).

2.2.6 Marking

- Open-ended contextualised questions had reputedly required a good deal of marker training and mark scheme development (Clausen-May, 2006).

3   Question 2 – What are the advantages and disadvantages of learning mathematics in context?

The question of whether it is advantageous to learn mathematics in context has been debated for many years. Boaler (1993b) explained that, from around the 1970s, there was a wide-scale adoption of mathematics textbooks and schemes made up from numerous examples of content in supposedly real-world situations. An example was the SMP 11–16 scheme which was used by around 85% of secondary schools in many parts of England and Wales. However, research identified by Boaler (1993b) suggested that learners performed differently when faced with "abstract" and "in context" calculations intended to offer the same mathematical demand. This may have been because the task the writer intended to communicate and the task the learner thought needed answering were quite different.

Other literature shows that advantages and disadvantages are associated with particular types of context when learning mathematics. These are given in more detail below.

The following research suggests that there are several advantages to various ways of learning in context:

- Completely integrated mathematics processes and content in open-ended activities resulted in learners:
    - retaining more of the learning after 6 months; the learners were more able to apply the correct methods regardless of context and there was a reduction in learners varying their mathematical procedure and performance due to the context of the question
    - developing mathematics knowledge that learners could combine, adapt and use flexibly
    - being able to interpret mathematics situations
    - achieving better GCSE results
    - achieving average scores on procedural and conceptual questions (Boaler 1993a).
- When time was allocated to discussing context, making connections between experiences, seeing how learning generalised and facilitating each learner's personal meaning of the mathematics, all helped learning. This was achieved in the classroom through:
    - discussions about the mathematics that learners did outside of school
    - activities in which learners self-generated methods, tested and discussed the methods.

These activities promoted deeper learning and transfer of learning (Boaler, 1993b).
- Real-world, local community or individual examples / contexts engaged and motivated learners (Boaler, 1993b).
- Information learned by children and adults in sparse question contexts was transferred to the real-world question context but not vice versa (Mevarech and Stern, 1997).
- Learning about fractions in a real-life context and then a geometric context enhanced learning (Khateeb, 2008).

- Real-world contexts were used in mathematics A Level programmes to discuss how mathematical modelling was useful. This helped learners develop insights. The contexts included synthetic contexts as they can be conceptualised as inefficient mathematical models (Little, 2010).
- Cognitively demanding tasks coupled with appropriately structured school dialogue promoted deep conceptual understanding (Imm and Stylianou, 2012).
- Familiar contexts (rather than unfamiliar contexts) had positive effects on learners' levels of inference-making (comprehension), motivation, and perceived difficulty (Song, 2011). This was because understanding an unfamiliar context required cognitive resources which would be allocated to understanding the mathematics encountered in a familiar context (Song, 2011).

The following research suggests that there are several disadvantages to learning in context:
- Mathematics learned in context was more difficult to transfer than mathematics learned in the abstract. Everyday mathematics problems could be encountered after learners had learned the abstract skills to solve the problem (Anderson, Reder and Simon, 1997).
- Considering underlying principles was more useful in facilitating links between school and everyday mathematics than learning in context was (Boaler, 1993b).
- Impractical, artificial or whimsical examples were found to undermine the claim that real-world contexts show how mathematics is useful (Little, 2010).
- Unfamiliar contexts were a barrier to particular groups of learners understanding and comprehending exercises, examples or questions. Therefore deep comprehension, motivation and the chances of success in learning were reduced (Boaler, 1993b; Song, 2011; Vurayai, 2012).
- "Everyday" contexts did not ensure that learners transferred the learning to everyday life (Boaler, 1993b).
- No context was universally accessible and therefore one learner's bridge was another's barrier. Thus, the same context helped some learners and hindered others (Boaler, 1993b).
- Signalling (non-content words that emphasise significant information) in contexts where the learners had high confidence in their knowledge reduced comprehension (inference making) (Song, 2011).
- Learning mathematics processes independently of content increased the likelihood of learners varying their procedure and performance in response to contexts, question layout and illustrations in questions, when compared with learning open activities that integrated processes and content (Boaler, 1993a).
- The factors determining whether a context is useful were complex (Boaler, 1993b).

4 Question 3 – Does the ability of the candidate influence the advantages and disadvantages of testing / learning in context?

There were only two key articles about how the ability of candidates influenced the above advantages and disadvantages of testing or learning in context.

Song (2011) studied the effects of different geographical background contexts on comprehension, recall and cognitive load (perceived levels of motivation, difficulty and mental effort). It was found that highly guided instructional material was sometimes redundant for more experienced learners, even though it was essential for less experienced learners.

Debba (2011) researched the effect of context in mathematics questions on Grade 12 learners' performance in a mathematical literacy test. It was found that low levels of reading literacy can be a barrier to understanding context.

5 Question 4 – What are the best contexts for use in mathematics exam questions?

According to Brown (1999), examination questions should concentrate on the essence of the school subject, and context is best used in projects and coursework when learners have a teacher to guide them. However, sometimes context is required in examinations. Therefore suggestions for developing high-quality contexts were derived from research findings. They are presented with the caveat that the construct being tested influences what makes a high-quality context. For instance, familiar contexts are more accessible to learners and could therefore be argued to be of high quality. However, if the construct to be tested is that of whether learners can apply mathematical principles in new situations, then using familiar contexts is invalid. Consequently the suggestions should only be followed if they do not compromise validity.

5.1 Realism

Contexts should:

- Present a realistic mathematical modelling scenario. Closed questions which ask about some of the process and numbers that are used to test the mathematical modelling can test learners' mathematical modelling and make marking less demanding (Clausen-May, 2006).
- Involve thinking within the context (Little, 2010).
- Involve tasks which provide a solution that is relevant and useful to the context (ie should be authentic) (Little, 2010).
- Present more than one mathematical model which learners are asked to compare, so that learners appreciate the relationship between reality and mathematical models. In such questions, synthetic contexts present limited mathematical models (Little, 2010).

5.2 Mathematical content

Contexts should:

- Generally be used for all data-handling questions, otherwise the question does not make sense (Fisher-Hoch et al, 1997).
- Align with the question content (Debba, 2011).
- Clearly align with the mathematical model (Little, 2010).

5.3 Typical contexts

Contexts should be based on scenarios which are typical for learners. Cresswell and Vayssettes (2006) claim the following are typically encountered in the lives of 15 year olds:

- Tasks involving quantitative, spatial, probabilistic or other mathematical concepts. For example, media outlets (newspapers, magazines, television and the internet) are filled with information in the form of tables, charts and graphs about subjects such as weather, economics, medicine and sports.
- Information on issues such as global warming and the greenhouse effect, population growth, oil slicks in the seas or the disappearing countryside.

- The need to read forms, interpret bus and train timetables, carry out transactions involving money and determine the best buy at the market.

5.4 Learners' experience

Contexts should:

- Be relevant to learners' lives (Debba, 2011; Song, 2011; Vurayai, 2012).
- Be familiar to learners (Boaler, 1993b; Song, 2011) rather than presenting adult metaphors (Boaler, 1993b).
- Be focused; the question should address the aspects of the context that will be most salient in real life for the learners (Ahmed and Pollitt, 2007; Little and Jones, 2010).
- Be restricted to those for which the everyday reasoning and the mathematical reasoning used to answer the question are the same (Ahmed and Pollitt, 2000; Debba, 2011).
- Use mathematics for the same purpose as the real-world situation upon which the context is based (Boaler, 1993b).

5.5 Resources (diagrams, graphs etc)

Contexts should:

- Use only relevant resources (Crisp et al, 2008) and avoid unnecessary information (Debba, 2011).
- Clearly provide the information needed to answer the question (Debba, 2011).
- Provide pictorial analogues which are powerful models to think with (Vappula and Clausen-May, 2006).
- Provide prompts to help learners remember the strategy to answer the question or provide the knowledge to answer the question (Fisher-Hoch et al, 1997).

5.6 Language

Contexts should:

- Be easy to read / have a low reading age (Debba, 2011)
- Use positive language (Crisp et al, 2008)
- Use clear, concise, unambiguous language which does not obscure the question (Little, 2010; Little and Jones, 2010).

5.7 Question layout

Contexts should:

- Avoid problematic question layouts (Debba, 2011). For instance, information should be presented in the order in which it is needed to answer the item (Fisher-Hoch et al, 1997) and each context should be unique to an item (Schroeder et al, 2012).

5.8 Teaching and learning

Contexts should:

- Reflect the learning environment, as the most valid measures of performance will be gained by learning and testing in similar environments (Boaler, 1993b).

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