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EXPERTS' NOTION AND STUDENTS' RESPONSES ON CONTEXT-BASED MATHEMATICS PROBLEM

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Abstract

Composing context-based mathematics problem (CbMP) is a challenge in educational practice. This study aims at exploring experts' notion and students' responses on the CbMP developed using PISA mathematics framework. An explorative study was undertaken to understand the nature of the developed CbMP from the notion suggested by experts from PISA, PMRI (Indonesian version of Realistic Mathematics Education), and experienced teacher. Data were collected from experts' comments on the CbMP as well as the responses of 70 students on the CbMP and a questionnaire. The comments were categorized and analyzed regarding the authenticity of context, plausibility, conformity to the profile of PISA task, clarity of information, and the use of language structure. Results indicate that the authenticity of the context and language structure becomes main issues commented in the CbMP. However, students' responses indicate the CbMP were able to attract their interest and seriousness when working on the CbMP. Also, more than 50% of students admitted activating most of the so-called Fundamental Mathematical Capabilities, in which reasoning and argumentation were recognized to be activated in solving the CbMP by most students.The state of experts' notion and students' responses on the CbMP are worthy to suggest teachers in composing context-based mathematics problem for mathematics instruction.

Keywords: Context-based mathematics problem, Mathematical literacy, PISA mathematics.

1. Introduction

Over the last two decades, the existing research in mathematics education has recommended examining how well pupils are able to apply their knowledge and mathematical skills to figure out mathematical problems embedded in meaningful real-world contexts [1]. Thus, the inclusion of context in problems used within instructional practices has been highly recommended by current reform mathematics curricula around the world. This reform is indicated by an international educational survey, namely PISA *(Programme for International Student Assessment)* (see, for example, OECD [2]) which emphasize on the connectedness of the instructional mathematical content by focussing on problem-solving and mathematical literacy. Consequently, context becomes one of the important issues discussed in the creation of composing mathematics problem, mainly in case of its relation with real world situation [3].

To compose mathematics problem, a suggestion has been given to teacher to understand the so-called 'Mathematical-task knowledge for teaching' dealing with the knowledge teachers need in order to select and develop tasks to promote students' conceptual understanding of mathematics, support their development of mathematical thinking, capture their interest, and curiosity and optimize the learning potential of such tasks [4]. This seems to support the idea of incorporating knowledge of context into the mathematical-task knowledge since a context should provide information that can be organized mathematically and should offer opportunities for students to work within the context by using their pre-existing knowledge and experiences [5]. In this study, the definition of context-based mathematics problem follows the definition offered by Wijaya [6], i.e. context-based mathematics tasks as tasks situated in real-world settings which provide elements or information that need to be organized and modeled mathematically.

However, we argue that composing CbMP, especially, would be challenging for teachers [7]. It is not only about making problem plausible to solve but also making problem authentic in which the real world included can be modeled mathematically satisfying the PISA mathematics framework. Thus, it is important for them to gain a broader insight on how to compose context-based mathematics problem for their instructional purpose from the perspectives of experts of context-based mathematics problem (CbMP). Therefore, this present study aims at understanding the nature context-based mathematics problem through the notion given by experts and responses by students dealing with CbMP.

2. Context-Based Mathematics Problem

Context-based mathematics problem cannot be separated by the inclusion of 'context' itself into problem being posed. Thus, the understanding of the nature of context is needed by a problem poser to compose problem that satisfies the characteristics of CbMP as suggested by PISA framework. It is clear that the contexts used in PISA must be familiar to the students, at least in the sense that a short text can provide enough information to have students feel confident that they understand the question [8]. Moreover, Stacey maintained that the items used in PISA should be authentic: as far as possible they should present students with the challenge of using mathematics in the way in which it is likely to be used in life outside of school. To that, Palm [9] asserted that the purpose of finding a solution for PISA problem needs to be as clear as it would be in the real situation. The language used should match with the real situation. The information given in the problem should be available in the real situation, and the numbers should be realistic. Students should be able to use methods that are available in the real-life setting, not only certain school content, the validity of solutions should be confirmed whether or not it makes sense with a real-world setting. Tout and Spithill [10] particularly mentioned the characteristic of PISA problem as follows. The problem should be rich and interesting for 15-year-olds around the world and was neither too hard nor too easy, has obvious authenticity and did not pose seemingly artificial questions, are as much as possible equally accessible and equitable for students of different gender, culture, religion, living conditions, use appropriate and accessible language.

3. PISA Mathematics Framework for Context-Based Mathematics Problem

The nature of CbMP used in this study follows the framework of PISA mathematics 2012. It is diagrammatically represented as given below.

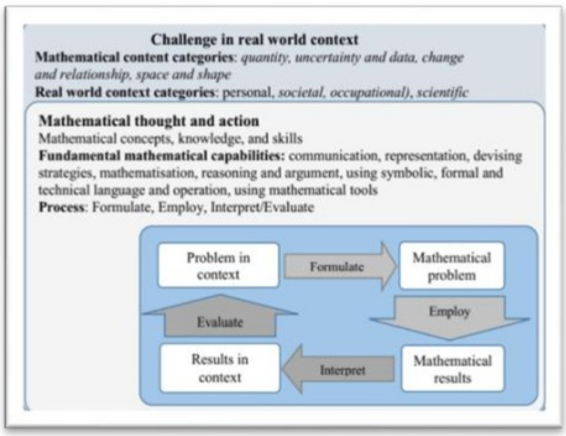


Fig. 1. A model of mathematical literacy in practice [2].

Figure 1 shows that mathematical literacy starts from a context-based problem, which is categorized into contexts: personal, occupational, societal, and scientific, and contents: change and relationship, space and shape, quantity, and uncertainty and data (see OECD [2]).The process of mathematical literacy begins from identifying the real world problem and formulate the problem mathematically based on the concepts and relationship inherent in the problem. Obtaining an appropriate mathematical form of the problem, the next step is to employ certain procedures to obtain mathematical results, which then interpret those back into the initial problem. In the process of 'formulate', 'employ', and 'interpret', the set of Fundamental Mathematical Capabilities (FMC) are activated successively and simultaneously in varying degrees depends on the related mathematics topics to obtain a solution. In the set of CbMP we developed, we used the features including content, context, and process categories from the PISA framework.

4. Research Method

To obtain data of experts' notion and students' responses on the CbMP, we initially developed a set of CbMP following PISA 2012 mathematics framework. Figure 2 shows how the CbMP were developed and evaluated by experts and students.

Generally, there were three steps in this study: composing CbMP, evaluating initial prototype from experts' review to get a revision, and using the revised prototype as explore students' responses. The steps summarized in Fig. 2 is elaborated as follows.

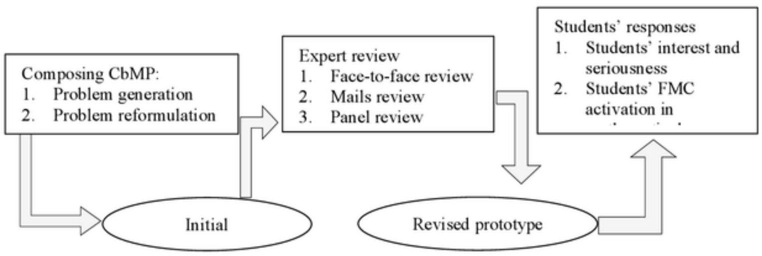


Fig. 2. Framework for developing and evaluating CbMP.

4.1. Composing context-based mathematics problem

To obtain a set of CbMP, we applied two problem posing techniques: problem generation (PG) and problem reformulation (PR) [11]. They respectively refer to the process of posing a problem based on a set of given information, and the process of posing a problem related to a problem that is or was the focus of problem-solving. We designed 11 CbMP with various combination of content, context, and process. Table 1 shows the profile of the CbMP.

Table 1. Profile of CbMP.

No	Unit of context	Content/Context/Process	Problem posing techniques
1	Trolley	SS/Soc/F	PG
2	Debit of coffee liquid	CR/Sc/I	PR
3	Failure of phone assembly	Q/P/I	PR
4	Body mass index	CR/P/E	PG
5	Body mass index	CR/Sc/E	PG
6	Body mass index	UD/Sc/E	PG
7	Biopori	CR/Sc/I	PG
8	Biopori	SS/Sc/F	PG
9	Biopori	SS/Sc/E	PG
10	Temple (a)	SS/Soc/I	PG
11	Temple (b)	Q/Soc/F	PG

Notes: CR=Change and Relationship; SS=Space and Shape; Q=Quantity; UD=Uncertainty and Data; P=Personal; O=Occupational; So=Societal; Sc=Scientific; F=Formulate; E=Employ; I=Interpret.

4.2. Participants

Participants involved in this study were secondary students grade 9 as many as 70 students and 12 experts who have experience in developing and/or reviewing CbMP. The experts are 2 Mathematics Expert Group (MEG) of PISA mathematics Australia, 8 PMRI experts, 1 PISA Indonesian researcher, and 1 experienced mathematics teacher.

4.3. Data collection

The expert review processes were conducted in three methods: face-to-face review, panel review, and mails review [12]. Face-to-face reviews were undertaken by giving the initial prototype to the experts to obtain responses so that we could confirm the responses from the experts directly. The review panel was conducted by discussing the items of CbMP with several experts at once. This was chosen because it can save time compared to interviewing the experts separately. Meanwhile, mails review was done by sending the prototype to the experts via email. Regarding students' responses on the CbMP, the data were collected after the students worked on the set of revised CbMP. They were asked to express what types of FMC they experienced during solving the CbMP. Their work on the CbMP was also examined to confirm the FMC they admitted to activate. They also were provided a closed questionnaire to confirm their interest and seriousness in solving the CbMP and also an open questionnaire to express their feelings to the CbMP.

4.4. Data analysis

The experts' comments were categorized and analyzed regarding the features of PISA problem suggested by the framework of PISA 2012. The features include (1) the authenticity of the problem; (2) the mathematical plausibility of the problem; (3) the conformity of the problem to the surface feature of PISA problem including (a) question format (multiple choice, closed constructed, open constructed), (b) process category (process, employ, interpret), (c) content category (quantity, change and relationship, space and shape, uncertainty and data), (d) context category (personal, occupational, societal, scientific); and (4) clarity of images, charts, table, and (5) language structure. Meanwhile, the students' responses regarding interest and seriousness to solve the CbMP were categorized using percentage showing to what extent the FMC was admitted to be activated during solving the CbMP. The written responses from the open questionnaire were analyzed by categorizing the responses based on the similar statements which support which FMC the students activated mostly.

As evidence on how they activated their FMC, we analyzed their written work on the CbMP by finding out how the three mathematical processes: formulate, employ, and interpret emerged in their work as well as how each of FMC was activated within those mathematical processes (See Fig. 1.)

5. Results

5.1. Experts' notion on the CbMP

Table 2 indicates the features considered as main issues reviewed by the experts. It is clear that authenticity and the use of language structure were mostly commented. To describe how the experts presented their comments to the CbMP, the following table gives an illustration of their comments and our decision to the problem being composed.

Table 2. Summary of experts' notion on the initial prototype.

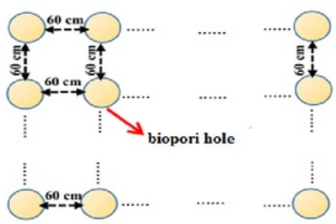
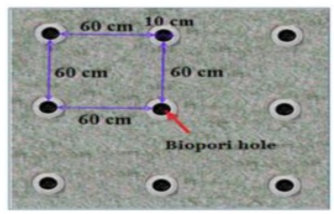
No	Unit of context	Features commented by experts
1	Trolley	1,4,5
2	Debit of coffee liquid	3(a)
3	Failure of phone assembly	3(b),5
4	Body mass index (a)	3(a)
5	Body mass index (b)	-
6	Body mass index (c)	4,5
7	Biopori (a)	1
8	Biopori (b)	4
9	Biopori (c)	1,2, 5
10	Temple (a)	1,3(a),5
11	Temple (b)	3(c),

Table 3. Experts' comment on the CbMP: An example Problem No 9.

Experts' comments
1. *"And realistically, can we assume that the entire space is available for the holes? Would you consider an acceptable solution to be placing the holes on an isometric grid so that ALL holes are the same distance from neighboring holes? In other words, if your objective is to maximize the number of holes, this layout is not optimal."* ***(authenticity)***
2. Revise the alternative of solution using a precise *mathematical* inequality. " *I can't follow your reasoning. A mathematical way to answer the 'fake' question is to set up an inequation like, let n be the number of holes, then* $10n + (n\text{-}1)60 \leq 600$, *and* $n=6$ *is the only integer satisfying this. But it does not take any of the real constraints and variables into account.* ***(mathematically implausible)***
3. Change 'design' into 'square pattern' ***(language structure)***
4. To be more realistic and clearly observed, change the model of design using images of real biopori hole on a grass area ***(clarity of images)***
Decision for revision
1. Change the word 'design' to 'square pattern' to explain that the arrangement of biopori hole is limited by the square pattern design, instead of free design
2. Revising the question becomes 'Using this design, what is the maximum number of holes that can be made by Zaki..."

Table 3 explains that there are three main issues commented by the experts, namely authenticity, the implausible of logic provided by the problem solution, and language structure. The implausible of logic, for example, is shown by the comment given to the solution which might seem incorrect as given by the inequality 10n + (n-1)60 ⩽ 600. Based on the comments shown in table 3, we then revised the item as shown in table 4 below.

Table 4. Problem no 9 before and after revision.

Before revision	After revision
Tony will make a number of biopori holes in his backyard. The backyard is rectangular measuring 4 meters x 4 meters. He plans to make the composition of the holes with the design as shown in the following figure.	Zaki wants to make a number of biopori holes having a hole diameter of 10 cm on the lawn behind his house. He plans to make the arrangement of the biopori hole with a square pattern as shown in the following figure.
	
What is the maximum number of biopori holes which can be made by Toni? Explain your strategy.	Using this design, what is the maximum number of holes that can be made by Zaki if the size of the field is 4 m x 4 m? Explain your strategy.

Based on the experts' comments from mails review, a general revision was made by improving the authenticity of the CbMP so that their context become more authentic instead of artificial, providing general information on each clearly stated unit of context, instead of writing the information down into each unit context-related question, and adding some items that have an easy level so that the tested items can be balanced in terms of difficulty level. Also, the experts also maintained that in one unit of the PISA context, the solution of the questions contained in the unit is not allowed to depend on each other. This is indicated by our experiences when developing the 'temple' context unit problem for the problem no 10, where problem no 11 in the same context was discarded and replaced with another problem whose cognitive demand of the problem is not related to the solution of the problem no 10. We also noted that the use of numerical values represented in mathematical symbols such as π (no. 7) is not suggested for CbMP, as it appears to be non-contextual in the real world. This is because it does not reflect the actual volume of waste.

In the panel session, we presented the CbMP to several experts. The main issue commented during the panel review, aside authenticity, is related to the language structure where we need to reduce the information that is too textual repetitive information. This suggestion was then applied for the problem no 1, in which the initial problem contains information about the design of trolley using long sentences instead of the figure. This session also emphasizes to consider the use of words/phrase that is not familiar with students. For instance, we give a short overview of what Body Mass Index (BMI) is, before further providing a more detail information related to the questions about BMI.

5.2. Students' responses on the CbMP

The students' responses were examined from the results of surveying their opinion about the FMC they admitted to activate supported by the data of students' work on the CbMP, and their seriousness and interest toward the CbMP. See table 5.

Table 5. The FMC admitted being activated by the students.

FMC admitted being activated	Percentage of students (%)	FMC admitted being activated	Percentage of students (%)
Mathematising	56	Devising problem-solving strategies	62
Communication	52	Reasoning and argumentation	80
Representation	64	Using symbolic, formal language	42

Based on table 5, it is known that 6 of 7 types of FMC were admitted to be activated by more than 50% of students in solving the CbMP. Among the 6 capabilities, reasoning and argumentation were recognized by most students (80%) when solving the CbMP. This recognition is in line with some of the students' written comments as follows.

Student 1: These problems require a lot of logic and is not fixated on formulas
Student 2:The questions need more reasoning than the problems I used to work which directly to the point (to answer I just need to use certain formula).

Meanwhile, there were respectively 52% and 64% of students admitted to *communication* and *representation* in solving the CbMP. The percentage of responses for communication that is not too significant is supported by the statement of some students who did find it difficult to explain the process of solving the problems. This seemed because they did not get used to writing the reason. This statement can be seen in the students' comments as follows.

Student 3: This is awesome to do maths by giving our reason on why and how I get the solution and it's quite challenging. Good.

However, from the response of student 4, it can be seen that representation was involved by using the figural model on the problem so that the students think more challenged to do it. This statement is also supported by other students' comments below.

Student 4: Interesting, because it's full of images, so it's easier to understand, although sometimes it is quite difficult to find the solution

Mathematising, on the other hand, was recognized by 56% of students. Some students admitted that they need to use their own way and even created their own formulas to find solutions. This is supported by the comments as follows.

Student 5:The problem can be worked with logic by creating your own formula from real life problem

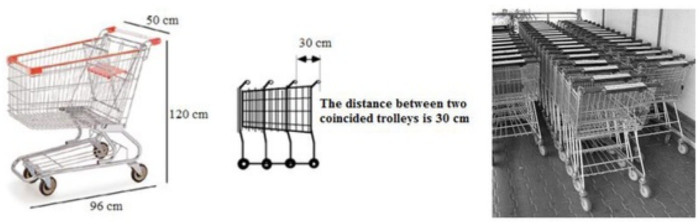
The FMC of devising and comparing strategies, on the other hand, was recognized to be involved by 62% of the students. The response of student 6 below indicates this FMC.

Student 6: I often only use one formula, but, it seems I need to modify several strategies, sometimes I got confused to use which one of the strategies fit with the solution of the problem.

The ability to use symbolic, formal, and technical operations were admitted to be involved by the students through using and manipulating certain mathematical formulas or procedures to obtain mathematical solutions. Table 5 indicates that only 42% of students who claimed to involve this ability. This is because students who do not need to use a lot of formulas, which is written in a symbolic form to solve the problem.

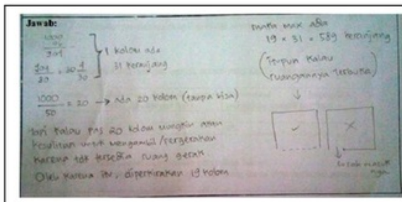
As the manifestation on how the students enacted their professed activation of FMC, we present one of the students' written works for problem no 1. This task shown in Fig. 3 examines students to formulate a mathematical model to determine the best approximation of the maximum number of trolleys.

The following figures show the design of a trolley for a market and a model of a room containing a set of trolleys. A trolley has a length of 96 cm and a width of 50 cm.



An open room having a measure of 10m x 10m is prepared for loading a number of trolleys for storage. Find the best approximation of the maximum number of trolleys that can be loaded by the room. Complete your idea by giving some mathematical calculations.

Fig. 3. Problem no 1: Trolley.



Translation

However, if it is 20 rows, it will find dificulty to make the trolleys move since there is no sufficient space. That's why it is approximately 19 rows.

Hence, the maximum number of trolleys is 19x31=589 units

Fig. 4. A student's work for task 1: Lia's case.

Figure 4 indicates that when activating communication, Lia receptively interpreted the meaning of textual and figural information about the size and arrangement of trolleys. She represented her idea by constructing the shape of an open room to load the trolleys. To devise problem-solving strategy, she started to find the number of trolleys, considered the space needed in between two rows, approximated the number of rows should be in the room, and finally determine the maximum number of trolleys. Thus, she constructed a mathematical model of the relationship between the number of rows and the number of trolleys for mathematising the problem. Reasoning and argument were activated by Lia through considering contextual information about the space needed for a set of trolleys to complete her chain of reasoning on finding the number of trolleys.

Regarding students' seriousness and interest toward the CbMP, table 6 summarizes the students' responses.

Table 6. Students' seriousness and interest toward the CbMP.

What is your comment after doing the question?	Percentage of Students (%)
I am interested and serious about doing all the problems.	34.28
I am only interested and serious about doing certain problems.	64.28
I'm interested, but not serious about doing all the problems.	1.44
I'm not interested in doing all the problems.	

Table 6 indicates that most of the students (98.52%, n=69) were interested in the CbMP they tried solving although 34.28% of them were not serious working on certain problems. This indicates that the problems in the CbMP actually has a potential effect on attracting students' curiosity in dealing with the context-based problem like in PISA, even though some of them are difficult to solve.

6. Discussion and Conclusion

The notion given by experts toward the CbMP seemed to concern mostly on the authenticity and language structure. This finding points out that the authenticity of context/situation of the problem becomes an important consideration for a problem poser to create CbMP. To get the authenticity of context PISA actually has recommended considering the level use of context. Thus, PISA has used almost no zero-order context items [13], i.e. the items whose context is a mere camouflage, generally involves just mathematical terms, shapes, data and the translation of textually packaged mathematical problems. Rather, PISA used first order and second order use of context, each of whose context is respectively relevant and is needed for solving the problem and the knowledge of context is needed to "mathematise" the problem in order to solve it [14]. Our experiences on turning 'camouflage' context to a 'more authentic' context suggest teachers to change the situation of the problem which seems only examine students' practicing mathematics skill to the situation where one really needs to solve the problem. For instance, for task no 10, we changed the question 'determine the number of temples as shown in the picture', which is meaningless in real-world setting, to question 'redraw the arrangement of the temple considering the number of temple and location based on the photograph of a concentric temple which was successfully taken by a photographer from the aircraft below'.

Regarding students' responses on the CbMP, the positive attitudes of students, as indicated by their seriousness and interest toward the CbMP, reveal that students will likely feel challenged if they are confronted with the problem containing genuine context rather than pure mathematics. This is in line with the finding of Venkat and Graven [15] reporting that their participants were more interested in doing mathematical literacy tasks rather than pure mathematics task because they think the connection to real life can be found within mathematical literacy task. Also, problems like CbMP can foster their mathematical competencies when solving problems. Thus, the CbMP has been indicated to have a potential effect on activating their fundamental mathematical capabilities.

To conclude, the experts' notion on the CbMP encompasses authenticity of context, plausibility, conformity to the profile of PISA task, clarity of information, and the use of language structure. It indicates that the authenticity of the context becomes the most important issue commented in the CbMP. Students' responses indicate the CbMP were able to attract their interest and activate FMC. To suggest, we would highlight that it is clear that teachers should consider the experts' notion in this study as guidelines when designing CbMP.

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