Journal of Physics: Conference Series **1402** (2019) 077105 doi:10.1088/1742-6596/1402/7/077105

Analysis of the mathematical learning materials with the characteristics of realistic mathematics education in the design research pre-service teachers' theses in Indonesia

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Abstract. This study focuses on analysing the theses of Mathematics Education Study Program especially the Design Research (DR) types to find out the relationship between mathematics learning materials with the characteristics of Realistic Mathematics Education (RME). DR is a research methodology aiming to develop local instructional theory. The emphasis of DR is on the process of designing and conducting instructional activities, also known as the Hypothetical Learning Trajectory. The relational analysis used in this study is error analysis. We observed and described alignment between the mathematical concepts, the instructional activity and the characteristics of RME in the DR theses. Using the relational understanding framework, we analysed 36 DR theses. The finding showed that some theses developed instructional activities which were not well- aligned with the mathematical concept taught, hence the relational understanding was not achieved. However, we also found that some theses developed instructional activities that were appropriate with the mathematical concept. In such cases, the students' relational understanding was achieved, and their mathematics learning outcomes were increased.

1. Introduction

This study focuses on analysing Design Research (DR) types theses of Mathematics Education Study Program at one Indonesian Teacher Education Institutions (TEI). Our goal is to find out the relationship between mathematics learning materials with the characteristics of Realistic Mathematics Education (RME). Research is one important element in Indonesian TEI curriculum. Thesis is a compulsory course for final-year pre-service teachers. In this course, a pre-service teacher is supervised by lecturers and conducts a research and writes a thesis. State University of Jakarta or Universitas Negeri Jakarta (UNJ) as one of the TEIs in Indonesia has been working to improve the quality of the pre-service teachers' theses. Especially at the Mathematics Department of UNJ, the thesis should have a direct impact for mathematics teaching and learning in schools. This is done by conducting different types of research methodology such as quantitative research and qualitative research (e.q. classroom action research, development research).

In 2010, the Mathematics Education study program, at UNJ encouraged its pre-service teachers to use Design Research (DR) methodology. DR lies under the qualitative research paradigm; its aim is to develop local instructional theory about mathematics learning. When first introduced at UNJ, DR was associated with Realistic Mathematics Education (RME). This was because at that time, UNJ involved

in *Pendidikan Matematika Realistik Indonesia* (PMRI) project – a Dutch RME adaptation in Indonesian schools [1]. Some research about RME teaching and learning used DR methodology, hence they became examples for Indonesian PMRI research. For the purpose of this paper, we define DR theses as the pre-service teachers' theses that used DR methodology. After almost nine years conducting DR, it is important to see whether the DR theses in UNJ have a direct impact to mathematics learning. This paper reviews the DR theses focusing on the relational analysis of the mathematical learning materials and the realistic mathematics.

1.1. Realistic Mathematics Education (RME)

The central principle of Realistic Mathematics Education (RME) is that mathematics should be meaningful for students, i.e. students can experience mathematics when they are solving a meaningful problem [2]. His idea was "mathematics as a human activity". It means that the mathematics learned by students should be close to students' reality and daily experiences. Therefore, students can make sense of their world and mathematics becomes meaningful for them. RME gives many opportunities for students to think and construct their own understanding. In RME, pupils are challenged to develop their own strategies for solving problems, and to discuss those strategies with other pupils.

Treffers [3] described five tenets of realistic mathematics education which are: (1) the use of contexts, (2) the emergence of models, (3) students' own constructions and productions, (4) interactivity, and (5) the intertwining of learning strands. The use of context brings mathematics closer to the students' daily life [3]. Context can be developed from students' everyday reality in which the mathematical concepts are embedded in. Context enables students to make sense of their world through mathematising [3, 4, 5]. The process of mathematising often allows students to model the situation by using mathematical representations such as drawing, graphs, diagrams, etc. The use of models helps students to move forward from the everyday world to the mathematical world [4]. Here, they start to use mathematical language and notations. This process support students' own construction of the mathematical concept. Students are the active learner who construct their own understanding. Teachers' role in RME classrooms is as the facilitator of the learning process. RME is underpinned by social constructivism, it believes that students would learn better in a socially interactive environment. The interactivity in RME classrooms allows students to share and discuss their ideas as well as support them to communicate their mathematical reasoning. Here, mathematical understanding is built together among the learning community. The last tenet is the intertwining, it highlights the interconnectivity of mathematical concepts, mathematics and other subject, mathematics and the everyday world. Therefore, the interactivity supports students to build an understanding of the connections within mathematical concepts or between mathematics and other subjects.

1.2. Design research methodology

Design research is a research methodology aimed to develop local instructional theory [6]. It has three phases which are repeated in a cyclic process [6, 7]. The first phase is thought experiment. It is where the researcher studies existing theorem and develop the learning activities. The researcher develops a hypothetical learning trajectory [8] which contains conjectures of students' learning. The second phase is instructional experiment. In this phase, the hypothetical learning trajectory is tested in authentic classrooms. The researcher observes students' learning and collects evidence of students' learning. The last phase is retrospective analysis. The researcher analyses the evidence of students' learning and compares them with the hypothetical learning trajectory to get insights into how the students build their mathematical understanding. It resulted in the refinement of the activity.

2. Methodology

This study uses content analysis methodology, especially the phenomenology exploration. The analysis focuses on the mistakes such as the misinterpretation, misuse, and misunderstanding of the implementation of RME in DR theses. By doing mistake analysis, this study will classify the mistakes to help understand what causes them.

This study conducted content analysis of DR theses written by pre-service teachers taking Bachelor of Education degree at Mathematics Education study program, UNJ. Data for this study were DR Theses of Bachelor of Education in Mathematics Education at Department of Mathematics, State University of Jakarta. The submission date of the DR theses was from 2010 to 2016, all together there were 36 theses.

The analysis focuses on the relational analysis on the context used in the DR theses and to find out whether they are appropriate for helping students build their mathematical understanding. To be precise, this study examined the pre-service teachers' misinterpretation, misuse, and misunderstanding of the contextual problem and the mathematical concept taught.

3. Results and discussions

This study aims to find out whether the pre-service teachers' DR theses used appropriate context in developing students' mathematical understanding. We conducted content analysis to 36 DR theses. First, we listed down all types of pre-service teachers' theses from 2010 to 2016. In general, pre-service teachers conducted quantitative and qualitative research. The quantitative research are mostly quasi-experiments. The qualitative research conducted by pre-service teachers can be categorised in four types – Classroom Action Research (CAR), Design Research (DR), Research and Development (R&D) and Evaluation Research. We listed down the thesis conducted during 2010 to 2016 and summed up that there were 164 theses used quantitative methodology, 112 used CAR, 36 used DR, 76 used R&D, and three theses used evaluation research.

Next, we conducted content analysis of the 36 DR theses. We focused on the context used in the lessons developed in the DR theses. To illustrate the analysis, we present ten DR theses in this paper. We chose these ten theses based on the variety of mathematical topics and the context used. Table 1 shows the context used in the DR theses.

Table 1. Context used in the DR theses.

No.	Thesis title	Context
1	*Design Research*: Learning Permutation and Combination with Social Constructivist Approach in Vocational Schools [9]	Using coloured paper and mixing paints to understand the concept of permutation and combination and to understand the differences between permutation and combination.
2	*Design Research*: Multiplication for Year 5 students at SDN 04 Klender Jakarta Timur [10]	Finding out the distance travelled by race cars in Karawaci race circuit by dividing the circuit into equal parts.
3	The implementation of PMRI to develop students' spatial visualization skills on volume of cubes and rectangular prism Year VIII-A SMP Negeri 2 Cilebar [11]	Using tofu as a unit cube to help students visualize the structure of a 3D shape, in this case a cube and a rectangular prism. Then students would develop different strategies to find the volume, i.e. the number of unit cubes in the structure.
4	Using PMRI to support students' conceptual understanding on system of linear equations concept at SMPN 1 Tambun Selatan [12]	The context of barter was used to help students understand equations, then they are guided to develop reasoning through exchanging to understand substitution
5	*Design Research*: The implementation of PMRI to develop students' relational understanding on sequence and series concept of Year IX at SMPN 74 Jakarta [13]	Using the context of fighter jets formation to help students understand number patterns. Then students move forward to learning the concept of sequence and series.

Table 1. Cont.

6	*Design Research*: the implementation of PMRI to develop instructional activities on direct and inverse proportion of Year VII at SMP Islam Al-Azhar 12 Rawamangun [14]	To help students understand the concept of direct and reverse proportions, the lessons starts with a context of the uniform of TNI. Other context was used, such as the time traveled by TransJakarta.
7	*Design Research*: the implementation of PMRI to develop instructional activities on addition of fraction by using number lines; Year VII SMPN 50 Jakarta [15]	Firstly, students explore the concepts of fraction and equivalent fractions. Then students explore ways to do addition of fractions in all cases of positive and negative fractions.
8	Developing students' learning trajectory on linear equation using PMRI in Class VIII-B SMP Muhammadiyah 4 Depok [16]	The context of online shopping was used to introduce the students to the concept of constant and gradient in a linear equation.
9	*Design Research*: Developing students' mathematical understanding on area of rectangle in Year VII SMPN 74 Jakarta [17]	The lesson starts with finding ways to find out the area of irregular shapes, then students were guided to use unit square to understand the concept of area. It then followed by the use of re-allotment strategy to find out the area of many different shapes
10	*Design Research*: the implementation of PMRI to develop students' relational understanding on function of Year VIII SMPN 13 Bekasi [18]	The concept of Function was introduced by using arrow diagram. Next, magic max box was used to help students understand the function, the domain, and the codomain.

The result suggests that even though the DR theses have developed contexts that are close to students' everyday life, there are still some context that seem inappropriate for the mathematical concepts taught. Table 2 shows the content analysis of the DR theses.

Table 2. Content analysis of the DR theses.

No.	Thesis Title	Content analysis
1	*Design Research*: Learning Permutation and Combination with Social Constructivist Approach in Vocational Schools [9]	Students could follow the activity of using coloured papers to understand the difference between permutation and combination. The arrangement of different colors helped students undertand permutation and combination. While mixing paints could show the number of possible color combination, it is not an appropriate context because after the paint is mixed, students could no longer see the permutation or combination.
2	*Design Research*: Multiplication for Year 5 students at SDN 04 Klender Jakarta Timur [10]	Dividing the race circuit to some equal parts was a good way to help students understand multiplication. However, it is difficult to divide a race circuit to some equal parts. This indicates that it is not an appropriate context.

Table 2. Cont.

3	The implementation of PMRI to develop students' spatial visualization skills on volume of cubes and rectangular prism Year VIII-A SMP Negeri 2 Cilebar [11]	Students observing the structure of a 3D shapes using tofu was a good start of the lesson. However, in reality even though tofu is shaped like a cube, it is not a mathematical cube. Therefore, this activity should really emphasis on the unit cube.
4	Using PMRI to support students' conceptual understanding on system of linear equations concept at SMPN 1 Tambun Selatan [12]	Barter might not be a convenient way of transaction nowadays. However, it is a good mathematical context to help students understand the system of linear equation. It can be used to help students understand equation with no constant $(ax = by)$, with constant $(ax = by + c)$, and the general form of linear equation $ax + by + c = 0$
5	*Design Research*: The implementation of PMRI to develop students' relational understanding on sequence and series concept of Year IX at SMPN 74 Jakarta [13]	Fighter jets formation and seat arrangement in a stadium can be used to help students understand the concept of number pattern. Stacking plastic cup helped students to find strategies of finding the n^{th} item of a sequence. Bricks arrangement in a stair way and the structure form by the bricks in the stair way helped students build understanding of series. This is an appropriate context.
6	*Design Research*: the implementation of PMRI to develop instructional activities on direct and inverse proportion of Year VII at SMP Islam Al-Azhar 12 Rawamangun [14]	Using the beads is realistic and it helped students understand direct proportion. Dividing the number of beads into equal groups helped students to understand inverse proportion. This thesis also discusses the examples and nonexamples of direct and inverse proportion.
7	*Design Research*: the implementation of PMRI to develop instructional activities on addition of fraction by using number lines; Year VII SMPN 50 Jakarta [15]	The number line was used to introduce students to fraction. When discussing negative fraction, realistic examples were used, such as negative temperature and the depth of the sea. This led students to negative fraction.

Table 2. Cont.

8	Developing students' learning trajectory on linear equation using PMRI in Class VIII-B SMP Muhammadiyah 4 Depok [16]	The thesis successfully used the online shopping context to show how linear equation is used to determine the total amount of money someone has to pay when doing online shopping ($y = mx + c$). y represents the total amount of money, x is the price of the item bought, coefficient m is the number of items bought and c is the shipping fee. However, the thesis did not discuss any cases when c is a negative integer.
9	*Design Research*: Developing students' mathematical understanding on area of rectangle in Year VII SMPN 74 Jakarta [17]	The re-allotment strategy was a new way to help teachers teach area of irregular shapes. Using re-allotment, students could rearrange any irregular shapes into a rectangle, therefore finding the area is easier.
10	*Design Research*: the implementation of PMRI to develop students' relational understanding on function of Year VIII SMPN 13 Bekasi [18]	*Magic math box* was used to introduce student to function. However, it did not help students to understand the concept of function. Students see $f(x) = ax + b$ simply as a linear equation. Therefore, the context has not really answered the challenge of teaching function.

4. Conclusion

This study examines the DR theses by focusing on the context used the theses. We used content analysis to see whether the context was appropriate for teaching the intended mathematical concept. Our findings show that even though all these theses used realistic context in their instruction, there are some theses in which the context was not appropriate. This might be caused by the difficulties of developing context that are mathematically appropriate and are familiar for students, as well as close to their everyday life. For example, even though tofu was not an accurate cube, it was still used as a context because it was familiar for the students.

This study also found that some DR theses used appropriate context. In these cases, the theses showed that the context supported students' learning. The students were able to learn actively and build their own understanding of the mathematical concepts. This study implies the need of having a group discussion among lectures at Mathematics Education study program to share a common ground of the contextual mathematics learning. It important for the lecturer to understand phenomenological exploration to help pre-service teachers develop appropriate context for mathematics instructions.

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