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Science, Mathematics, Engineering and Technology Education — Cultural Challenges and Opportunities in a Globalising World

Proceedings of the Eighth International Conference on Science, Mathematics and Technology Education

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Edited by
Rekha Koul
Curtin University, Australia

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Proceedings of the Eighth International Conference on Science, Mathematics and Technology Education
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PREFACE

The Eighth International Conference on Science, Mathematics and Technology Education was held in Jakarta, Indonesia in November, 2015. The theme of the conference was ‘Science, Mathematics, Engineering and Technology Education – Cultural Challenges and Opportunities in a Globalising World’ and it was organised jointly by the Science and Mathematics Education Centre, Curtin University, Australia and Universitas Negeri Jakarta, Indonesia.

The conference provided an intellectually challenging and culturally enriching experience for science, mathematics and technology teachers, teacher educators, researchers and administrators from primary, secondary and tertiary education from around the world. It was for the first time that this particular conference or any other international conference in SMTE was held in Indonesia. The Universitas Negeri Jakarta conference featured the largest number of presentations, participants and workshops and the largest number of participating school teachers. This was a rare bilingual conference in Bhasa Indonesia and English in mathematics and science education.

Over 157 abstracts were received from different countries and most states of Indonesia and 137 accepted. The participant representing 11 different countries were from Australia, Canada, Indonesia, India, Malaysia, Mexico, Nepal, New Zealand, Oman, Philippines and Saudi Arabia. The conference took place from 21-24 November 2015, starting with the one-day workshops on 21 November by presenting 6 facilitators, namely David Henderson, Melissa Loh, and Kaitlyn Panzich for workshop 1; Esther Matemba and Natalie Lloyd for workshop 2; and Elisabeth Rukmini for Workshop 3. Keynote speeches were delivered by Prof. Dr. David Treagust from Curtin University; Emeritus Prof. Paul Ernest from University of Exeter; and Prof Lilia Halim from Universiti kebangsaan Malaysia. All three keynote speakers authority in their own specialization presented thought provoking ideas in interesting manner. Invited speakers: Prof. Dr. Zainal A. Hasibuan (The Head of National Education Standards Board/ Badan Standar Nasional Pendidikan (BSNP), Sri Rahayu, Ph.D (Head of Postgraduate School of Science and Chemistry Education, Universitas Negeri Malang, and Dr. Anton Noornia (Head of Postgraduate School of Mathematics Education, Universitas Negeri Jakarta) appraised international delgates with current trends in educational research in Indonesia. On the sidelines of the conference be tour to visit Taman Mini Indonesia Indah was held, a place that represents Indonesia, where delegates appreciated the diversity and culture of ethnic groups in Indonesia.

These proceedings are a result of the papers presented at the conference. All papers contained in the proceedings were presented at the conference and consequently submitted to a reviewing process. Each paper was reviewed by at least two referees. The papers have been organised alphabetically in these proceedings.

We have continued our mode of publication as an electronic form. However, people may order a book of the proceedings by contacting one of the editors.
ACKNOWLEDGEMENTS

The conference would not have been possible without the support of Science and Mathematics Education Centre, Curtin University, Australia and Universitas Negeri Jakarta, Indonesia.

We would like to thank all the authors who contributed their papers to these proceedings. We would also like to thank the reviewers and particularly the members of the Editorial Board for their time and diligence.

The book represents contributions from many nations including Australia, Canada, India, Indonesia, Malaysia, Mexico, Nepal, New Zealand, Oman, Philippines and Saudi Arabia. We acknowledge the contributions of people from all these countries. The fields of science, mathematics and technology education research represent a truly international endeavour.

Rekha Koul and Yuli Rahmawati
Editors
November, 2016
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REALISTIC MATHEMATICS EDUCATION (RME) AS AN INSTRUCTIONAL DESIGN APPROACH FOR MAN 4 JAKARTA ELEVENTH GRADER STUDENTS MAJORING IN SOCIAL STUDIES TO BUILD RELATIONAL UNDERSTANDING OF INTEGRAL

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Abstract. Calculus is a branch of mathematics that is studied in Senior High School. Integral is one of the subjects in Calculus, but the Instructional Design Approach of Integral Learning in MAN 4 Jakarta is not contextual yet and lack of relational understanding development. The purpose of this research is to develop a Local Instructional Theory using RME as an Instructional Design Approach to build students’ relational understanding of Integral. This research is using the Design Research Method which consists of three cyclic phases which are preparation and design, teaching experiment, and retrospective analysis. The contexts that are used in this research are the derivative of a function, wall paper, and the definition of a function. The retrospective analysis shows that the context used, mathematical process, and the activity of the students and teacher proved to be able to build students’ relational understanding, with contexts as the tools in thinking activities from “model of” to “model for”. The result of this research is proved by the ability of students to explain the fact of the process and results of his/her work.

Keywords: RME, relational understanding, Integral, wall paper.

INTRODUCTION

The mathematics learning objectives in Indonesia correspond to the NCTM (National Council of Teachers of Mathematics): 1) problem solving, 2) reasoning, 3) communication, 4) connection, and 5) representation, that can be achieved by learning mathematics in school from elementary, junior high, to senior high school. Students of twelve graders of MAN 4 Jakarta still have difficulties in several mathematical materials, such as Integral in Calculus. The difficulties that experienced by the students correspond with the 20 years of research compiled by Kizito (2012), that the students don’t have the relational understanding about Integral, yet. Students could solve and answer procedural problems, but struggle to solve the conceptual problems, and they didn’t even try to solve it. It was probably caused by the learning process. Anthony and Walshaw (2009) stated that learning activities which lack of students engagement will cause the students struggle to be able to solve mathematical problems. The learning objectives can be achieved by building a condition of fun learning and learning understanding using context that can be the previous understanding (Heuvel-Panhuizen, 2001), which can be achieved by using the Realistic Mathematic Education (RME) approach. RME uses guided reinvention method and contextual problem (Gravemeijer, 1999). The context gives the opportunity to students to develop mathematical understanding by changing from “model of” to “model for”. Students can do an intertwinement that connects the new math material with the math material which had been understood, followed by interactivity with other students and teacher.

Solving a math problem with a self-chosen strategy, can be conducted with relational understanding. Relational understanding in this research is reconstructed from Skemp by Kinach (2002): 1) Content level understanding, 2) Concept level understanding, 3) Problem solving level understanding, 4) Epistemic level understanding, Relational understanding occurred when someone can use a mathematical procedure using the mathematical concepts that he/she has understood, and then can make the relation among what to be learnt with what has been understood. Learning with the Realistic Mathematics Education (RME) approach can give the opportunity to construct the relational understanding. The local instructional theory of Integral subject using RME approach can be built using a Hypothetical Learning Trajectory by a Design Research. According to that, the Design Research: Realistic Mathematics Education (RME), as an Instructional Design Approach for MAN 4 Jakarta Eleventh Grader Students Majoring in Social Studies to Build Relational Understanding of Integral was conducted.

According to the reconstruction of understanding from Skemp by Kinach (2002) and the Minister National Education Indonesia number 22nd year 2006 about content standard for Elementary and High Education Unit, the development of relational understanding is restricted to: 1) content level understanding (can show the basic facts using algorithm), 2) concept level understanding (can analyze and synthesize patterns), 3) problem solving understanding (can
use scientific method to solve problem independently), 4) epistemic level understanding (can give valid mathematics proves). The mathematics content in this research is the Integral for social studies major in MAN 4 Jakarta: 1) Indefinite Integrals; and 2) Definite Integrals.

The purpose of this research with a Design Research method is to develop Realistic Mathematics Education (RME), as an Instructional Design Approach for MAN 4 Jakarta Eleventh Grader Students Majoring in Social Studies to Build Relational Understanding of Integral. The research use for students is to escalate the quality in mathematics learning process in Integral with Realistic Mathematics Education (RME) As an Instructional Design Approach for MAN 4 Jakarta Eleventh Grader Students Majoring in Social Studies to Build Relational Understanding of Integral. The strategy and learning design that developed in this research can be used as an alternative in teaching. Teachers can use the Local Instructional theory in this research, so he/she can be more focused in doing the fun learning activities effectively.

THEORETICAL REVIEW

Realistic Mathematics Education

Realistic Mathematic Education (RME) was developed since 1971 by the mathematician Hans Freudenthal in the Netherlands. Gravemeijer and Terwell (2000) support this learning approach with their opinion that learning mathematics will be more meaningful for students if started with the investigation about man activities. Furthermore, Heuvel-Panhuizen (2001) explain that realistic is not only a situation in the real world, but also things that can be visualized by students such as stories and formulas. Using contexts help students to construct mathematics concepts, because the new mathematics concepts that have to be learnt is easy to be connected with the prior knowledge. In order to achieve understanding, activities to connect the new knowledge to the prior knowledge is important since mathematics is not to be given as a final formula that is ready to be used (Gravemeijer and Terwel, 2000). Understanding can’t be given by teacher to students. It has to be constructed independently by students (Lynn, 1999). Understanding can be constructed by directing students to reinvent mathematics ideas or concepts by mathematical process by solving realistic mathematics activities. This is supported presentation by Heuvel-Panhuizen (2001) that when working with contextual problem, students develop mathematical process and understanding.

Gravemeijer (2000) stated that the RME principles are:

a. Guided reinvention an progressive mathematization, to find the independent way to solve mathematics problems
b. Didactical phenomenology (the use of phenomena in learning math)
c. Self-development model

The principle of RME is supported by five characteristics presented by Treffers (in Gravemeijer, 1994):

a. Using context
The context not only as an illustration, but furthermore the contexts are really used as the tools to reinvent mathematics context. Heuvel-Panhuizen (2001) presented that context is the important thing in learning use the RME approach, since has the functions as follows:

1. Concept forming gives the opportunity to students to reinvent concept naturally using context.
2. Model forming make the context can be used by student to develop many strategies to reinvent mathematics concept.
3. Sufficiently flexible to be applied makes the context can give the opportunity to students to see the application of it in the real world
4. Fit with the students’ informal strategies means that Students use context to explore and to explain about the solution using context as the tools to solve problem.

b. Use models to Progressive Mathematization
c. Using the Students’ Construction
d. Interactivity
e. Intertwinement

Figure 1. Reinvention in RME

Gravemeijer (2000) stated that the RME principles are:

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According to those experts’ opinion, so the learning activity that use the RME approach has to be started with context from the real life of the concepts that had been understood by the students, and then followed by the discussion to solve the problems to get the solution of the problems, eventually student can reinvent the mathematics concepts independently.

**Integral Learning**

Ryan (2005) presented that Integral is a part of Calculus. The definition of calculus is parts of mathematics that analyze the aspects of changing in process or system that can be modeled by function, using two primary tools namely derivatives and integrals. Differentials and integrals emerge from the idea of limit; develop from the function concept in the intervals decreasing to almost zero. The relation between differential and integral, known as the fundamental theorem of calculus, founded at the end of 17th century independently by Isaac Newton and Gottfried Wilhelm Leibniz. Purcell (1996) presented that the fundamental theorem of calculus connect the gradient problem with the wide area problem. Indefinite Integral is an anti-differential.

**Instructional Local Theory**

The purpose of this design research is to develop a local instructional theory to construct relational understanding students in the realistic mathematics frameworks, which serves as a theory that is proven empirically on how a series of learning activity can be used for students majoring in social studies to build the relational understanding on Integral. According to the presentation above, so this design research is arranged in 6 stages:

1. Using the relational understanding that Integral is an anti-differential with the model of is polynomial function which the term in the polynomial function which consist of only a constant stated with two factors the characteristic and the variable powered by zero, to explain why the indefinite integral has to be added by a constant noted by C.
2. The second stage is using the relational understanding with the model of is the function that pass through a point \((x, y)\) to find the value of the C in the anti-differential function.
3. The third stage is a guided reinvention on a concept of wide area as the limit of additional the wide areas of rectangular which the wide of each rectangular very close to zero, so the numbers of the rectangular is near to infinity in the interval \([a, b]\) that use the model of hang wall paper.
4. The fourth stage consists of activities to do the algebra manipulation using integral to find the wide area between graph and x axis in interval \([a, b]\).
5. The fifth stage is using the relational understanding with the model of is the definition of a function. The students understand the definite integral using substitution.
6. The sixth stage is using the relation understanding with the model of is the differential of the function of multiplication of two function, as the tools to understand the partial integration.

**Hypothetical Learning Trajectory**

Hypothetical Learning Trajectory is made to clarify the Local Instructional Theory into mathematics learning activities in each meeting. There are nine meetings of learning, and one meeting of test in this design research.

**RESEARCH METHODOLOGY**

Bakker (2004) stated that design research has three phases: (1) preparation and design (thought experiment); (2) teaching experiment (instruction experiment); and (3) retrospective analysis (produce conjectured local instructional theory), that form a cyclic process in each phase also in overall of the design research.
This research is conducted in the second semester of year 2015/2016 at MAN 4 Jakarta. According to the criteria of choosing the research subject such as the prior ability, the activity of students in the teaching experiment phase, so it was chosen six research subjects. Then it was discussed with the observer whether those six students are suitable to be chosen.

The data collected in this research is the video recordings, photos, students’ work, and field notes (log). The methods to collect data are: pencil and paper methods, interview methods, and ostensive methods with video tape. The research instruments are: (1) video tape, (2) work sheets, (3) audio recording, (4) fields notes, and (5) Hypothetical Learning Trajectory Validity and reliability in this design research is needed to get the research result that can be proven right and valid. There are two kinds of the data: validity ecology validity and internal validity. And there are two kinds of data reliability: external reliability and internal reliability.

Interpretation framework is the part that explains the method used to analyze data of research result that is the series of learning process in the class community that related with the development of mathematical process. Gravemeijer (2006) stated that there are two criteria in interpretation framework, that is (1) the framework to interpret the development of students mathematical thinking process as the overall in a class, (2) the framework to interpret the development of students’ mathematical thinking as an individual.

**RESEARCH RESULT AND DATA ANALYSIS**

The following will be explained about the process of learning experiment in class and the data from it will be analyzed. The data analysis using the Emergent Perspective Interpretation Framework and will be explained for each meeting.

**First Meeting: Integral as anti-differential**

By using the idea that \( \frac{\mathrm{d}}{\mathrm{d}x} x^n = nx^{n-1} \) in discussion activities, students reinvented that since the differential of any constant was zero, the students found that the anti-differential of zero could be any constant number. By working backward the student find the pattern that anti differential of any polynomial function has to be added by a constant that noted by C.

**Second Meeting: Determine the Integral of function that passes through the point \( (x_0, y_0) \)**

The students used the definition of gradient as the context in this meeting, and then use the definition of function that passes through a point.

**Third Meeting: The exercise on Integral as anti-differential and determine the function of Integration.**

The students asked to solve the open ended question about indefinite integration. Then by using the relational understanding in the discussion, the students can find which function that can be the answer, either which function that can’t be the answer. The students also can apply that in the graph, to explain about the possible answer.

**The Fourth meeting: Understanding Integral as a wide area**

Having the students had the prior knowledge about the wide area of regular shapes, learning activity continued with the challenge to cover a wide area of a wall that has irregular shape with wall paper. The video of how to hang wall paper was presented to the class.
The students then filling the worksheets on determining the wall paper needed to cover the area of the wall that the shape is a quarter of the circle area if the wide of the wall paper are 1 unit wide, 0.5 unit wide and 0.1 units wide. The students then analyze the results to answer which total area needs was the nearest to the wall area that has to be covered. After finding the result the students get the further question what will it be with the total area of the wall paper, if the wide of the wall paper decreasing? If the wide of wall paper is zero, what is the total area of the wall paper? So, what is the minimum wide of wall paper to get the nearest total area to the area of the wall that has to be covered? Amazingly, the students work on these tasks entirely, although they did not use to work on essay task. By actually doing this task, the student can analyze and come up with an idea that the technique on how to hang wall paper that the teacher offer will not be satisfied by the costumer since there will be area which not be covered.

The following activity is the teacher introducing the formal notation on what the students has been working on, as follows:

$$\lim_{\Delta x \to 0} \sum_{i=1}^{n} f(x_i)\Delta x = \lim_{n \to \infty} \sum_{i=1}^{n} f(x_i)\Delta x = \int_{a}^{b} f(x) \, dx$$
Formula 4.1. Definite Integral

By actually working to calculate the total wide area of wall paper with different wide, the students easily saw the idea of \( \int_a^b f(x) \, dx \) that affect to the increasing of the wall paper numbers that directed to the idea \( \lim_{n \to \infty} \frac{b-a}{n} \). Students can easily see that using integral to determine the wide area is only the other way to find the wide area that is more effective to be used on irregular shapes.

The fifth meeting: Determine the wide area between above x axis and a graph and the wide area between under x axis and a graph

Using the wall paper, makes the students easily see the wide area has to be a positive value, since there is the wall paper needed to cover it.

The Sixth Meeting: The exercise on Definite Integral

Find the wide area of a) and b) using integral.

![Figure 7. Problem adapted from Rosken and Rolka (2007)](image)

The problems were not the regular problems but the problems that needed the understanding and can be solved without any algebra formula.

The seventh meeting: Integral with Substitution

By using the definition of a function, students were easily solving the problem in this part.

The eighth meeting: Partial Integration

Since the students were already getting used to use their relational understanding to connect their prior knowledge with the new knowledge that has to be learnt. The students were working backward to find the result of Partial Integration.

The ninth meeting: The exercise of Integral Procedural understanding

The procedural understanding still needed to be mastered, since it is a part of relational understanding. The interesting thing that happened was the students could solve problems more independently.

The tenth meeting: Test the relational understanding of Integral

The test consists of four problems that are about the indefinite integral, analyzing the result of definite integral of a function, analyzing the wall paper needed to cover the wall, and analyzing the wide area between two curves.

Data Analyze

Research Subject (RS) Analyze

RS1 has a very good prior knowledge about differential content. He/she was the one who first find the pattern that lead to the idea of adding C as the constant value to the integral of a function, by using the definition of anti-differential as the context. Followed by the activity in the fourth meeting where RS1 could understand the idea of the activities were to compare the wide area that were calculated by the prior knowledge formula and by the integration formula using wall paper as the tools to connect both formula. RS1 can solve all the four problems in the tenth meeting, it means that RS1 mastery all the indicators of relational understanding and then the five indicators of RME. The indicators of relational understanding and five principles of RME also mastered by RS2, RS3, RS4, RS5, and RS6.

CONCLUSION AND SUGGESTION

Conclusion

These learning activities that give the students the opportunity to reinvent independently build the ability of students to find their own mistakes. The use of context makes them easier to find the mistakes. Compare to the students who had done exercises on procedural problems who still can’t get the idea that the area under the x axis has to be a positive value. So, if student is an iceberg, then the design research can reveal the potential of the iceberg under the sea surface that is bigger than the potential of the iceberg above the sea surface. The other finding in this design research is
the students’ works show that students try harder to solve the problems not just writing “I don’t know” in their answer sheet.

**Suggestion**

1. Suggestion for teachers are:
   a. Teachers’ role to guide students to follow the hypothetical learning trajectory. The consistency of teacher as facilitator has to be maintained, so the students realize that in the learning activity each students has to have an active role to understand the content and reinvent the concept independently
   b. Teachers have to really pay attention on the direction of context changing to formal mathematics, and give the guidance to ensure the reinvention.

2. Suggestions for other researchers are:
   a. Wall paper installation requirement must be changed into hang it until the highest point of the curve.
   b. The other researcher can develop the local instructional theory in this design research such as learning using the multimedia in an online classroom.

**REFERENCES**


