

HOW A REALISTIC MATHEMATICS EDUCATION APPROACH AND MICROCOMPUTER-BASED LABORATORY WORKED IN LESSONS ON GRAPHING AT AN INDONESIAN JUNIOR HIGH SCHOOL

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This study focuses on the applicability of ICT-supported lessons based on a Realistic Mathematics Education (RME) approach in an Indonesian classroom context. The topic chosen for the research experiment was pupils' graphing skills, with emphasis on graph interpretation and with the application especially to kinematics. One class was involved in this study and 13 - 14 years old pupils used the specially designed materials and activities. This included the use of motion detectors in pupils' experimental work. The authors investigated the expectations, performances, and opinions of the pupils and the teacher with respect to the activities and analyzed pupils' thinking and understanding in the reformed setting. The results of the classroom experiment indicated that the pupils made remarkable progress in their performances that can be attributed to the chosen approach. The pupils' and the teacher's opinions on the teaching and learning activities in general also appeared to be positive.

Note

The first author conducted this research study as her final project in the International Master Program in Mathematics and Science Education at the AMSTEL Institute, University of Amsterdam.

INTRODUCTION

Although mathematics is considered important in all stages of education, Indonesian pupils' performances in this subject is generally still poor: for instance, Indonesian 8th graders ranked 34th among 38 participating countries in the TIMSS-R assessment (Mullins, Martin, Gonzalez, Gregory, Garden, O'Connor, Chrostowski, & Smith (2000). The poor performance on the international stage also held for science and technology. It does not seem likely that the intelligence and capacity of Indonesian children are worse than those of children from other countries. We are of the opinion that the main cause lies in the current instructional setting.

Indonesian mathematics education faces another problem: most pupils' attitudes towards mathematics are negative. Most of them perceive mathematics as difficult and boring. This is not surprising when we look closely at the common practice of teaching and learning mathematics in Indonesian classrooms. A diagnostic survey conducted by the Ministry of Education and Culture in 1996 revealed that despite many reform efforts, teacher-centered learning focusing on procedural knowledge is still the norm. Teachers actively explain materials and provide examples and exercises, while pupils only listen, write, and perform the tasks initiated by the teachers. Discussion, interaction, and communication are seldom conducted. Mathematical goals and curriculum materials are still based on the mathematics of mathematicians, and they lack real life application. More recent research that was conducted to identify Indonesian problems (Zulkardi, Nieveen, van den Akker, & de Lange, 2002) confirms this educational picture and mentions various causes, including inaccurate learning materials, inadequate mechanistic teaching methods, poor forms of assessment, and pupils' anxiety about mathematics.

Another problem of Indonesian mathematics education is its lack of touch with Information and Communication Technology (ICT).

This is a pity because research indicates that ICT is a good catalyst for the realization of alternative setups such as an activity-based approach or a realistic approach to mathematics and science instruction.

One of the ongoing developmental research efforts is to adapt the instructional design perspective of RME to the teaching and learning of mathematics in Indonesia (Fauzan, Slettenhaar, & Plomp, 2002; Hadi, Plomp, & Suryanto, 2002). In the concept of RME, mathematics is a human activity connected with reality. Context problems, i.e. problems in which the problem situation is experientially real to the pupils, are used as starting point in learning. By giving pupils opportunity to use their own informal strategies in solving the problems and to discuss with teacher and fellow pupils, the process of understanding is stimulated. RME seemed to the authors a promising approach to tackle some problems of mathematics education in Indonesia. The authors also thought that ICT tools could be used to support the process for pupils of coming to grips with mathematics.

The authors decided to design and test ICT-supported teaching and learning activities that were based on the RME approach. The design was used as a replacement of part of the chapter "Time, Distance, and Velocity" in a popular Indonesian mathematics textbook. The focus was on graphing skills with emphasis on graph interpretation and with application especially to kinematics. One of the main reasons for choosing this topic is the frequent complaint of teachers in various fields about the lack of pupils' competence in interpreting graphs. The instructional design concerned some characteristics of the RME approach and used a Microcomputer-Based Laboratory (MBL) environment – in the authors' case, the "Coach computer learning environment" (Heck, 2002) – in the teaching and learning activities. Besides the focus on enhancing students' learning, the design was also tested for the purpose of ascertaining how this teaching and learning model worked in an

Indonesian classroom context. This included organizational aspects, teacher and pupil classroom behavior, and teacher and pupil opinions of the activities. Moreover, the teaching and learning activities and the materials designed and developed in this study might become a model for later use by teachers. Results of the study might also reveal some aspects that should be considered when implementing RME based and/or technology supported lessons.

THE RESEARCH PROJECT

The major concern in this research study is the applicability of the designed teaching and learning activities. The research questions are:

- a) *How applicable is the teaching and learning activity based on an RME approach to a graphing topic with application to kinematics in an Indonesian second grade junior high school classroom?* In particular, the authors were interested in the way the pupils and the teacher behaved during the activity and in their opinions about the RME approach.
- b) *How does the implementation of MBL-based instruction work in lessons on kinematics graphs in an Indonesian second grade junior high school classroom?* In particular, the authors wanted to find answers to the following questions about the MBL approach: Does it help to correct pupils' alternative conceptions in graphing? How do the pupils and the teacher behave in the MBL environment and what difficulties do they experience? What are their opinions about the MBL approach?

Regarding the research questions, the authors expected the following to occur during the teaching and learning activities:

- a) Concerning the RME approach: Pupils will talk more actively and become more aware of their mathematical thinking. The situational problem as the starting point helps pupils to relate what they learn to problems in daily life. The class

environment becomes livelier. The teacher might have difficulty in the beginning to adjust to his new role in the activities; e.g., he might have problems with guiding the class discussion because this is new to him.

- b) Concerning MBL: It enables pupils themselves to construct and interpret graphs that are related to real situations, and this helps to correct their alternative conceptions in graphing. The laboratory set-up encourages pupils to become engaged and to be more enthusiastic in the work. There might be technical problems related to the MBL environment or to the teacher's capability to master it in a short time.

PREVIOUS RESEARCH AND THEORETICAL FRAMEWORK

The research background of this study consists of three elements: results of research on graphing, the philosophy of Realistic Mathematics Education, and the theory and practice of the use of Microcomputer-Based Laboratory in mathematics and science education.

Graphing

In the world where fast, accurate, effective, and efficient exchange of data and information is needed, methods of displaying trends and relationships between variables are very important. Weintraub (as cited in McKenzie & Padilla, 1986) stated, "Graphs present concepts in a concise manner or give at a glance information, which would require a great deal of descriptive writing. They often distill a wealth of information into a small amount of space" (pp. 571 - 572).

Graphing skills are also thought to be one of the critical topics that are important and fundamental to other more sophisticated parts of mathematics as well as to other disciplines (e.g., see Beichner,

1994; Clement, 1985; Lenton, Stevens, & Illes, 2000; McKenzie & Padilla, 1986). Of these skills, graph construction and interpretation have been identified as important.

However, pupils are likely to have difficulties in graphing, especially when dealing with interpretation tasks. Research conducted by Lenton, Stevens, & Illes, (2000) on 14-15 year old pupils showed that construction of graphs was generally done well by this year group, but that interpretation of data was often less accurate. There have been many similar findings, most of which deal with kinematics, i.e., the motion of objects (e.g., Beichner, 1994; Clement, 1985; McDermott, Rosenquist, & van Zee, 1987; Mokros & Tinker, 1987).

Research has identified the following alternative interpretations and conceptions that pupils have in graphing:

- *Variable confusion.* Pupils do not distinguish among variables. They often believe that graphs of these variables should be identical; they appear to readily switch labels on axes from one variable to another without recognizing that the graphed line should also change (Beichner, 1994).
- *Interval/point confusion.* In interpreting graphs, pupils often narrow their focus to a single point, even though a range of points (an interval) is more appropriate. This is most apt to occur if the wording of a question is ambiguous, especially concerning use of the word "when." Nevertheless, their focus on a single point seems to be part of an overall tendency to interpret graphs point-wise (Leinhardt, Zaslavsky, & Stein, 1990).
- *Height/slope confusion.* Pupils have been found to confound these two graphical features on both interpretation and construction tasks (Leinhardt, Zaslavsky, & Stein, 1990). They often confuse gradients with maximum (or minimum) values – reading values off the axis and directly assigning them to

the slope. An example of such an error is the use of graphical feature of height instead of slope to represent speed in a distance-time graph.

- *Iconic interpretation* ('graph as a picture' error). Pupils sometimes interpret a graph of a situation as a literal picture of that situation. A frequently cited finding in this regard is pupils' interpretation of travel graphs as the paths of actual journeys. Clement (1985) divided it into two categories:
 1. Global correspondence: when the shape of an entire problem scene is matched to the shape of the entire graph in a global manner.
 2. Feature correspondence: when a specific visual feature of the problem scene is matched to a specific feature of the graph.

REALISTIC MATHEMATICS EDUCATION (RME)

Realistic Mathematics Education was first introduced and developed by the Freudenthal Institute in the Netherlands where it is still under active development. It is based on the view of Freudenthal (1991) that mathematics is a human activity and that reality can be used as a source for mathematization. Zulkardi (2002; after Treffers, 1987) provides the following characteristics of RME:

- *Use of contextual problems.* It is important to use real contexts that are meaningful and natural to pupils as a starting point for their learning, allowing them to become immediately engaged in the situation. Instruction should not start with the formal mathematical system and end with an application or related context problem as a kind of add-on to be studied after the appropriate mathematics has been learned, perhaps in order to conclude the learning process. On the contrary, the phenomena in which the concepts appear in reality can be taken as anchoring points for concept formation. Also,

'real contexts' and 'reality' should not be understood primarily as problem situations from real life or the real world; rather, they refer more to situations that are experientially real to pupils and/or something real in their minds.

- *Use of models or bridging by vertical instruments.* In solving problems, pupils develop and use models as a bridge between abstract and real. At first it is a *model of* a situation that is familiar to the pupils. By a process of generalizing and formalizing, the model eventually becomes an entity on its own and is used as a *model for* mathematical reasoning.
- *Use of pupils' contributions.* Pupils should have the opportunity to produce more concrete things themselves and to develop their own informal problem solving strategies. The teacher and the instructional materials guide a bottom-up reinvention process of the pupils. The process by which a given piece was invented in the history of mathematics may be a source of inspiration for the teacher and for the designer of the instructional materials.
- *Interactivity.* Interaction among pupils and between pupils and teacher is an essential part in RME because discussion and collaboration enhance reflection on the work (Gravemeijer, 1994; de Lange, 1995). In an interactive instruction pupils are engaged in explaining, justifying, agreeing and disagreeing, questioning alternatives, and reflecting.
- *Intertwining of learning strands.* In the philosophy of RME, various mathematical topics should be integrated in one curriculum. Pupils should develop an integrated view of mathematics as well as the flexibility to connect to different sub-domains and/or to other disciplines. This demands connection among strands, to other disciplines and to meaningful problems in the real world.

Thus, RME is more than “using real life contexts in mathematics education.” Its main points are *guided reinvention*, *didactical phenomenology*, and *emergent models* (Gravemeijer, 1998). We restrict the further discussion of RME here to two aspects, viz., the mathematization and the use of pupils’ informal strategies and own productions. More detailed descriptions of RME can be found in Freudenthal (1973, 1991), Gravemeijer (1994, 1998), Treffers (1987), and at the website www.fi.uu.nl/en/rme.

In mathematics education the focus is quite often on mathematics as a closed system. But organizing phenomena by means of progressive mathematization, i.e., by considering mathematics as a human activity, seems more important in the learning of mathematics. Treffers (1987) distinguished two kinds of mathematization: *horizontal mathematization* refers to modeling experientially real situations into mathematics and vice versa, whereas *vertical mathematization* refers to the process of attaining a higher level of abstraction within mathematics. In other words, horizontal mathematization is a process in which pupils translate problem situations that they perceive as real or realistic into some mathematical system. They invent or use mathematical tools to organize and solve their mathematical problems. In the end they translate mathematical results back into underlying statements of the problem situation, and they reflect on the work they have done. Vertical mathematization, on the other hand, concerns reorganization within the mathematical system itself like, for example, finding shortcuts, generalizing methods, and making connections between concepts and strategies. Freudenthal (1991) stated it in the following way: “horizontal mathematization involves going from the world of life into the world of symbols, while vertical mathematization means moving within the world of symbols.” In RME mathematization takes place in both directions by means of a

reinvention process that is guided by the teacher and by the instructional materials.

Treffers (1987) classified mathematics education into four types with regard to the presence (showed by a checkmark) of horizontal and vertical mathematization, as presented in Table 1.

Table 1
Classification of Mathematics Education Type According to Treffers (1987)

Type	Horizontal mathematization	Vertical mathematization
Mechanistic	-	-
Empiric	√	-
Structural	-	√
Realistic	√	√

The *mechanistic* approach is based on drill practice. Mathematics is seen as a system of rules and algorithms; doing mathematics is analogized with machinery works which means verifying and applying these rules to problems that are similar to previous problems (Wubbels, Korthagen, & Broekman, 1997). This approach is dominant in Indonesian schools. The *empiric* approach sees the world as reality. Pupils are confronted with materials from the real world in which they have to do horizontal mathematization, but they are not prompted to extend a situation in order to come up with a formula or model. According to the *structural* point of view, mathematics is an organized, deductive system. The learning process in mathematics education is guided by the structure of this system and has nothing in common with the learner’s living world.

The *realistic* mathematics education approach is based on a different point of view of mathematics education. The main difference with the mechanistic and structural approaches is that RME does not start from abstract principles or rules with the aim to learn to apply these in concrete situations (Wubbels, Korthagen, &

Broekman, 1997). On the contrary, much importance is attributed to informal strategies and constructions that pupils develop themselves. They form the most natural way for pupils to attack problems and RME makes use of this in the instructional design of lessons. The art of teaching according to RME is to give pupils the opportunity to produce more concrete things themselves and to take their own productions as starting points for the mathematization and the gradual formalization of the informal strategies. The general idea behind this is that by making free productions, pupils are forced to reflect on the path they themselves have taken in their learning process and, at the same time, to anticipate its continuation (de Lange, 1995). Thus, in lesson work pupils are encouraged to realize and identify mathematical aspects in their daily life and to give meaning to problems from a real world context. They are challenged to develop their own strategies and approaches for solving the problems and to discuss them with fellow pupils. The teacher's role here is more one of facilitating pupils' learning through the so-called "guided reinvention" process in which pupils reflect on their own strategies in a follow-up discussion facilitated by questions from the teacher. In essence, the pupils are in a RME approach very actively involved in the development of their relational networks of mathematical concepts.

MICROCOMPUTER-BASED LABORATORY (MBL)

Microcomputer-Based Laboratory is equivalent to the UK English term "computer-based data logging." Computer-based data logging consists of computer tools for measuring data in practical work. One needs sensors, an interface, and a computer with an application that can present the data as tables and graphs. Physical quantities such temperature, force, current, voltage, light intensity, motion, sound, pressure, and so on, are measured with sensors whose signals are digitised and fed into the computer through an interface. After

data are collected and stored in the computer, they can be processed, analyzed and presented in tables and graphs. One major goal of this data manipulation is to aid in the interpretation of graphs. Data processing and data analyses are often considered as a part of MBL.¹

Many researchers have already done research studies on using MBL-based instruction to enhance pupils' graph interpretation skills in various contexts. According to reviews done by Lapp and Cyrus (2000) and Lapp and Moenk (2001), some research has suggested positive results in this respect. Various contexts were used in the research projects including chemical concepts (Nakhleh & Krajcik, 1991), heat energy and temperature (Linn, Layman, & Nachmias, 1987), and kinematics (Brasell, 1987; Mokros, 1985; Thornton, 1996; Thornton & Sokoloff, 1990; Svec, 1999). Mokros and Tinker (1987) identified the following characteristics of the MBL-tools that are important to enhance pupils' interpretation of graphs:

- MBL uses multiple modalities. In learning through MBL pupils experience the materials in many different ways. They have kinesthetic experience by manipulating physical lab materials and probes and sometimes using their own physical features or movements as data. These are reinforced by visual (and sometimes audio) as well as analytical experience. The multi-modal approach enables pupils to use their strong intelligence or learning styles and encourages them to build up learning modalities that are weak.
- MBL provides a real-time link between a concrete experience and the symbolic representation of that experience. It may form a bridge between concrete and formal operations. Barclay (1985) mentioned that the fast feedback allows pupils to relate immediately the graph to the event. Linn, Layman,

¹We refer to Tinker (1996) for a broad overview of the use of MBL in science education.

& Nachmias (1987) and Thornton and Sokoloff (1990) made similar statements.

- MBL provides a genuine scientific experience for pupils. For instance, pupils gather and analyze real data. Mokros and Tinker (1987) viewed learning about graphing within real contexts and pupil-controlled experiments as analogous to learning about grammar by writing.
- MBL eliminates the drudgery of graph production. This advantage allows pupils to focus more on exploring the data and its representations. Rather than doing time-consuming tasks associated with data collection and display, pupils can spend more of their laboratory time in observing physical phenomena and interpreting, discussing, and analyzing data. Thornton and Sokoloff (1990) also supported this point.

Especially in a kinematics context it appears that the immediate display of the real-time graph production, along with pupils' ability to control the environment and the kinesthetic experience, play a vital role (Lapp & Moenk, 2001). It is speculated that experiencing the movement while watching the graph helps pupils to form a link between the two.

The computer application used in the activity design of this research was Coach 5,² which is under continuous development at the AMSTEL Institute in the Netherlands. This computer learning environment provides several possibilities for active, self-responsible study of natural and mathematical phenomena by pupils, such as:

- carrying out measurements, immediately displaying results of measurements, processing data;
- controlling apparatus (e.g., a lamp or a motor);

² For further details about the Coach 5 environment see: <http://www.science.uva.nl/research/amstel/> or <http://www.cma.science.uva.nl>

- setting up computer models, investigating relationships between physical quantities, making predictions and comparing these to real life data;
- collecting position-time data from moving objects in digital video clips or in a sequence of pictures

The sensor used by the pupils in this study was the Ultrasonic Motion Detector (UMD) which measures distance by emitting ultrasonic pulses and by determining the length of time it takes for the reflected pulses to return. It was connected to the computer via the Coach Lab II interface.

DESIGN OF CLASSROOM ACTIVITIES

Before developing the instructional unit we analyzed the chapter "Time, Distance, and Velocity" of the mathematics textbook (Adinawan & Sugijono, 2000) that teacher and pupils used in class. We restricted ourselves to the part that discusses motion graphs, i.e., the section on drawing distance-time graphs and the section on graph reading. We identified the following graphing skills regarding distance-time graphs:

- Skills required for creating graphs:
 1. choosing scales;
 2. drawing and labeling axes;
 3. plotting points (from table or context) in a coordinate system;
 4. understanding the connection between a graph and a table
- Skills required for analyzing and interpreting graphs:
 5. point reading and the meaning of coordinates;
 6. interval reading and what it means;

7. knowing the meaning of zero slope;
8. interpreting the steepness of parts of a graph;
9. determining the slope of a straight line and relating it to average velocity;
10. determining the intersection of graphs and relating it to the situational context

The textbook supports the teaching of these skills through drill and practice.

The authors also applied the classification of tasks on graphing of Leinhardt, Zaslavsky, & Stein (1990). For each task found in the examples and exercises we wrote down its type (prediction, classification, translation, or scaling), its category (construction or interpretation), its perspective (local or global), its character (quantitative or qualitative), and its focus (e.g., point reading, interval reading, graph feature, and so on). The conclusions were:

- All tasks in the section on drawing distance-time graphs are combinations of translation and scaling, belong to the construction category, have local perspective and quantitative character, and focus mainly on the coordinate system.
- All tasks in the section on graph reading are translations of interpretation type and quantitative character. Two-thirds of these tasks relate to local properties and focus on one quantity through point reading. The other tasks mostly focus on interval-reading and deal with global properties such as stopping time and average velocity on a certain time interval, i.e., involve the use of two or more values extracted from the graph.

So, tasks of prediction or classification type and tasks of qualitative character were not present in the textbook. The findings from the analysis also indicated some omissions in this widely used

textbook that we consider as important aspects of creating and viewing a graph:

- sketching a graph, e.g., from a narrative description of the situational context;
- describing a given graph in simple words, e.g., using a graph for communication purposes;
- global understanding of a graph and connecting it to the situational context, i.e., seeing a graph not as just a nice picture, but realizing that it is a concise representation of information and a useful mathematical tool;
- relating a distance-time graph to a velocity-time graph (as a first example of different types of graphs that describe the same phenomenon)

A teaching and learning activity was then designed to take into account the instructional goals already found in the textbook (skills 1 to 10) and the extra skills listed below:

11. sketching a graph, given a textual situational context;
12. making a textual description of a given graph in a related real situation;³
13. knowing that in reality time cannot move backward to zero and that actions do not happen instantaneously; and
14. drawing a graph related to a given graph, in particular, making the connection between a distance-time graph and a velocity-time graph.

With the instructional goals in mind and guided by the theory of RME we developed an instructional unit on motion graphs. In the lessons pupils would start with practical works using their own

³ This is supposed to be achieved by giving a predicted graph of motion and asking pupils to describe the motion.

movements as a source of data (made possible by the MBL environment) and as a starting point in their learning. This experimental set-up was chosen to allow pupils to become engaged immediately in the situation that connects “real life” to mathematical concepts. It involves horizontal mathematization. The practical work was meant to be done in-groups of two or three pupils and to be followed by classroom discussion to ensure interaction among pupils and between teacher and pupils in order to encourage talking about mathematics and mathematical thinking. For the same reason, the pupils were asked to write lab reports of their practical works. All these reflect the RME ideas of “interactivity,” “guided reinvention,” and “use of pupils’ own contributions.” The end point of the unit was a small investigation task for which pupils were asked to give a presentation of their results. This reflects the RME idea that pupils need to have room for exploration and for construction of their own products and strategies in order to build up their own theory. The intertwining of learning strands was taken into account in the instructional unit by making connections to other disciplines and to meaningful problems from the pupils’ real world.

The instructional unit was designed for four classroom meetings of two hours. In the first meeting the teacher would introduce the pupils to the MBL-environment Coach and to the ultrasonic motion detector (UMD). The idea was to actually invite the pupils to get involved in the introductory experiments, thus giving them the opportunity to become acquainted with the hardware and software. Classroom discussions about the way things work and about the meaning of the graphs produced would play a key role in the first meeting. Pupils would practice in this introductory meeting the already taught skills required for creating graphs. The experiments would also serve the purpose of preparing the pupils for their practical works in the next two meetings. The compulsory practical works in these meetings are listed below, together with the graphing

skills that are addressed in them (using the above numbered list of skills).

1. Investigate the difference of the appearance of the distance-time graph and of the velocity-time graph while you walk steadily and while you walk with changing speed (faster, slower, and at random). Skills: 5, 8, 11, 14.
2. Find the characteristics of the distance-time graph and velocity-time graph when you walk fast, slow, and when you stop. Skills: 6, 7, 8, 14.
3. Walk the graph, i.e., simulate a motion that produces (as similar as possible) some given graph. Skills: 5, 6, 7, 8, 9, 12, 14.
4. Walk the graph (continued) or explain why the given graph cannot be a motion graph. Skills: 12, 13.
5. Explore (with 2 UMD) how the diagrams will look if you record the simultaneous motion of two objects and plot their distance-time graph in one picture. Skills: 5, 10.

Pupils would conclude their practical work with a short investigation task that they could choose from a list of five:

1. Investigate the motion graph of a bouncing ball.
2. Draw and describe the distance-time graph of your trip from home to school.
3. Compare the distance-time graph of a boy and girl in a walking race.
4. Compare the height vs. age diagram of East-Asian boys and girls (Internet data).
5. Compare graphs of temperature in two different regions during a week (Internet data).

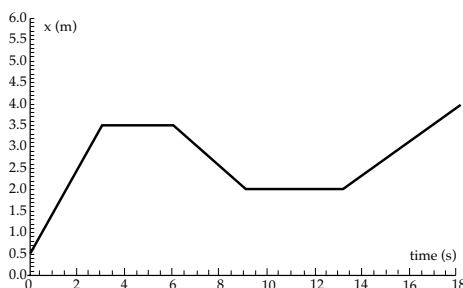
Pupils would be asked to prepare a presentation of their results for the final classroom meeting in which their lab notes would be

discussed and the results of the investigation tasks would be presented.

To support the teacher and pupils during the teaching and learning activities, we developed a Teacher’s Guide and a Pupils’ Guide. The section in the Pupils’ Guide for Practical Work 3 is shown below and is representative of the kind of tasks given. Note that this text was also made electronically available to the pupils in the form of a Coach activity, which allowed us to prepare the graphs to be matched beforehand.

Goal of Practical Work 3:

In this activity, you are asked to simulate the motion to produce (as similar as possible) the graph to the right:



Steps of Practical Work 3:

First, describe what you think you should do by answering the following questions:

1. How far from the detector should you start?
2. How far from the detector should you finish?
3. How many times should you stop and how long each time?
4. How long should you walk before the first stop?
5. When (in which time interval) do you walk at highest speed?

6. Determine the velocity in each time interval (0 to 3, 3 to 6, 6 to 9, 9 to 13, 13 to 18)

Now, try to walk that way. Is your prediction correct? Try several times until you get the best result. Copy down the resulting $x-t$ and $v-t$ graph on the experiment worksheet or save it in Word.

Have a look on the $v-t$ graph. Compare the result with your answer to question 6.

7. If there is any difference, why do you think that is?
8. If you continue to walk with the same velocity as the last time interval, when do you think you will be 6 meters away from the motion detector?

RESEARCH DESIGN AND METHODOLOGY

Participants

The research took place from January to March 2002 at SLTP Ciputra,⁴ a junior high school located in Surabaya, East Java, Indonesia. One of the reasons for choosing this school was that it is well equipped for conducting the classroom experiment. It has a computer laboratory with enough computers for a complete class and with a beamer that can be used for demonstrations and for pupils' presentations of their results.

One class of the second grade level of junior high school with 23 pupils (13 males and 10 females, all between 13 and 14 years of age) was involved in the study. There were four parallel classes at this grade level, but the grouping of these classes was not based on the pupils' performance level. So, in the particular class, pupils' performance varied from low, middle, to high achievement level.

⁴ For further information about Ciptura School, see their website: <http://www.schoolciptura.com/>

The class had one mathematics teacher who was also the mentor of this class. He was and is a young teacher, who at the time of the research was in his second year of teaching at the school. Before that, during his teaching training period, he had given private mathematics tutorials to high school pupils. At the time of the research study, he taught mathematics in four classes, two classes at the first grade level and two classes at the second grade level, and he taught the particular topic for the second time in a school setting. The teacher was acquainted with the RME idea, but he admitted that the notion was still not clear to him and his other colleagues. There were some differences in their understanding of the RME idea. For the ICT aspect, he reported that he was quite familiar with it, but seldom used it in his mathematics lessons. The only time he used ICT was by asking his pupils to search for some information about a particular mathematical topic on the Internet.

METHODS AND INSTRUMENTATION

The research experiment was set up in a classroom situation. The pupils made use of the designed classroom activities. The validity of these activities (e.g., whether their contents indeed reflect the school curriculum) was discussed one month before with Indonesian mathematics teachers. The activities were also tried out with some mathematics and science teachers at SLTP Ciputra shortly before the experiment took place. This led to some changes in the Pupils' Guide to make it less difficult and more suitable for the pupils.

The authors gave pre- and post-tests to the pupils to investigate the effect of the ICT-rich RME-based instructions on the pupils' graphing skills. The designing of the pre- and post-tests was based on some sources, e.g. Test of Graphing in Science (TOGS) developed by McKenzie and Padilla (1986) and some research papers by Mokros and Tinker (1987) and Lenton, Stevens, and Illes (2000). These tests contained 8 items and were scheduled for one hour.

Answer sheets were prepared so that pupil would not only select an answer from various options but also explain the reasoning behind choosing or not choosing an option. The pre-test was tried out on some non-participating pupils of the same age in order to ascertain the understandability and the time aspect of the test. The pre- and post-test results were scored in terms of a percentage using a predetermined weighting scheme. It should be noted that the marks depended strongly on the reasoning given by the pupils and that, therefore, subjectivity in marking was unavoidable. Since we were more interested in the improvement of graphing skills of individual pupils rather than in the comparison of pupils by their marks, we considered the pre- and post-tests as useful tools for finding out the effects of our teaching and learning design on the pupils' performance in graphing.

The authors selected three pupils, one each from low, middle and high achievement levels (according to the teacher), to do the pre- and post-test in a special setting in which they were invited to think aloud and were interviewed separately. In this way we hoped to obtain a better overview and understanding of the pupils' mathematical thinking.

The authors developed pre- and post-questionnaires to learn more about pupils' opinions on teaching and learning activities in mathematics before and after the actual classroom meetings. These questionnaires contained both Likert-type items and open-ended questions regarding RME and ICT aspects. Results of Likert-type items were reported in a percentage format, whereas open-ended items were analyzed and summarized.

The authors interviewed the teacher before and after the instructional unit had been used. We did this to ascertain his expectations before the pupils' activities and his evaluation and suggestions after the classroom meetings. We used the interviews

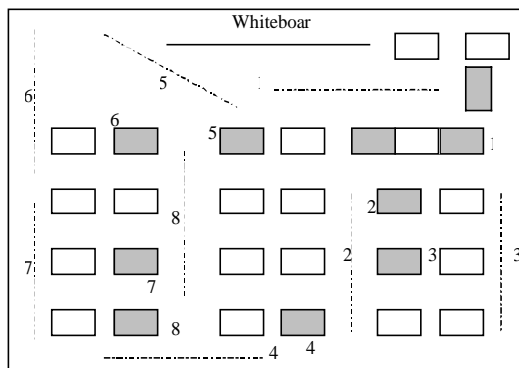
with the teacher in our assessment of the applicability of the teaching and learning design.

Other sources of data were the pupils' reports of their practical works and the observations made during the classroom meetings and the pupils' presentation sessions. The observation protocol consisted of taking field notes about each group's method and progress in doing practical works, pupils' discussions, and interesting events in each meeting.

THE CLASSROOM MEETINGS

In this section the authors give a short impression of how the classroom meetings went. For a written meeting-by-meeting account we refer to the extended research report (Widjaja, 2002).

The very first meeting suffered severely from two things. Firstly, due to a school event, the teacher had found little time to prepare the lesson and to acquaint himself well enough with the software and equipment. Secondly, the computer lab could only be used for one lesson hour of 40 minutes, which was really too short for this introductory lesson. Although the pupils evinced some concern about this, they nevertheless showed great interest in the software and equipment as well as in the upcoming practical works. The first meeting was repeated one week later, but now for the full 80 minutes and with a better preparation by the teacher. This time everything as well with one exception: it turned out that the computer laboratory was not spacious enough for 8 groups of 23 pupils in total and 3 adults to work simultaneously in an effective way. The motion detector was limited to short distances, the surrounding tables and computers were in the way, and the groups could not avoid hindering each other during motion experiments. We made a design for optimal use of the space in the computer lab (see Figure 1), but after trying this out the following class meeting,



it became clear that the only viable solution was to split the class into two.

Figure 1: Set up of the computer laboratory (dimension: 9m x 8m). The rectangles represent computers (Coach 5 was installed in the shadowed ones) and the dashed lines represent the pupils' walk paths. The numbers indicate which group was assigned to which computer and which walk path

While doing their practical work, some groups took measurements by placing the ultrasonic motion detector (UMD) on top of a stool, table, or monitor. Others did them by asking one of their group members to hold the UMD while another member walked in front of it. The difficulty most pupils faced in the beginning was how to adjust their movement so that they could produce a good and smooth graph. In the beginning they tended to walk too fast. They they realized that by doing so, either they could not walk any further even though the preset measuring time was not over, or that they moved too far from the detector so that it could not detect them anymore. Some pupils changed the experiment setting and shortened the measuring time; others just walked more slowly. One unexpected problem problem remained;

the UMD seemed to function only with a pupil whose body was broad enough to be detected easily. This forced groups with only skinny members to 'borrow' a fatter person from another group to do the motion.

The teacher usually walked around in the classroom, observing the groups and having discussions with them. Almost every time he came to a group, questions arose from group members, mostly about what had to be done. This indicated that pupils still were not used to, or felt a bit insecure about, the new role of active, investigative learners. They still seemed to prefer that the teacher instruct them on what to do, rather than to read the Pupils Guide and find out by themselves. The teacher tried to refrain from intervening in pupils' experiments, giving instructions, or giving hints and answers to questions too easily.

The activity which pupils found most difficult was Practical Work 3: "Walk the Graph" (shown on the example of practical work). There were two reasons for this: First, before going on to this particular activity, pupils got a separate text explaining the velocity concept. After studying this text, they could continue with the Pupils' Guide and do another experiment. Here we made too strong an appeal to pupils' ability to read theory and the practical guide independently and to link them with one another. As a result, pupils felt insecure and tended to ask what to do, what the meaning of something was, and so on. Second, producing a graph similar to a given one is not easy. One has to pay attention to many things, like whether to move forward or backward, whether to move slow or fast, and in the meantime, has to pay attention to the distance. Our pupils had the same expected difficulties, even more so because of lack of space and, sometimes, technical problems with the equipment.

During the practical work, pupils not only collaborated with members of their group but also with members of other groups.

Encouraged by the fact that one group had finished, some groups asked for extra hours to complete their own tasks. This interest in other pupils' work was also revealed when some groups did their practical work in the Internet corner of the school library because of scheduling problems for the computer lab. Hence pupils from other classes and even from senior high school were very interested in what happened, had a look, and commented that they would very much like it if they also got that kind of activity in their mathematics lessons.

Because of the shortage of time, the tight school schedule, and the pupils' various stages of work, the teacher and the first author decided to modify the last part of the teaching and learning design. As an assessment, the groups would do their presentation of the 6th task in pairs instead of in a class discussion format. Two groups would be assessed at a time, one of them presenting their results and the other giving comments, and vice versa. The presentation session was held in the computer laboratory. The teacher assessed all presentations, and the researchers were present merely as observers. Some groups gave good presentations and were quite confident when reporting their results. They also made good comments that showed their understanding of features of graphs. Others were a little clumsy when making their presentation and had some confusing discussions with the teacher because of misunderstandings. These pupils used quite a lot of improper terms when presenting results and answering questions. In general, the teacher's questions to pupils during the presentation session were mainly asking them to describe what they had been doing in the activity and how they had gotten the required data for the tasks. Then he would inquire about some details, and based on the question in the activity, he would demand explanations on how they found the answers. During the presentation, sometimes it seemed that the teacher asked unrelated questions, and unfocused

discussion followed as a result. In spite of this, in general the assessment ran smoothly.

FINDINGS AND ANALYSIS

Information from all data sources was examined in relation to the concerns and questions of the study. Results are presented in this section. Readers interested in more details can find them in the extended research report (Widjaja, 2002).

Pupils' and Teacher's Behavior in the RME-Based and MBL-Supported Activities

The most noticeable new aspect in the classroom setting was its interactivity, one of the main RME characteristics. It was no longer the teacher who actively took control of everything and determined what to do, but it was the pupils who in doing this became more responsible for their own learning process. Nevertheless, this was new for pupils and they were not yet accustomed to it. They tried to read and follow the Pupils' Guide, but most of the time they tended to ask for exact guidance on what to do. Instead of inquiring and finding out by themselves, they asked the teacher what some things were meant to be, what the answers were for the questions, and so on. That they were accustomed to teacher-centered learning was also seen from comments made in the open-ended items of the post-questionnaire: some pupils expected the teacher to explain the topic to them in a detailed way.

When working on their tasks, some pupils were more persistent than others. They insisted on doing several trials again and again until they got satisfactory results, whereas others tried to manipulate the situation to get expected results. Nevertheless, it is of interest that, when given more self-responsibility, pupils were more concerned to do their tasks well. The pupils were actually the ones who proposed extra time to continue and finish their work.

In group-work, most pupils could collaborate well and were willing to do so. At the least, they divided the tasks and did their own favorite part, but mostly they did all the tasks together and took turns in doing the motion, handling the software, and typing the report. When giving the presentation, they also divided the duties (who would give the introduction, who would present the graphs, and so on), and they assigned a fair time for each member to present his/her part. There was a sort of competition between some of the groups, but not in a negative manner. They just liked to do the tasks faster and better than the others did. On the other hand, cooperation not only happened within groups, but it also happened between members of different groups. This consisted of helping other groups with their tasks when necessary, of discussing among one another, and debating answers to the questions.

The discussion and debate between pupils and the teacher was also something noticeable. Not only during the practical work sessions, but also during the presentation session, pupils did not hesitate to express their own views or their own thinking, even when they differed in opinion with the teacher. On the other hand, discussion between the teacher and pupils was not as intense as we expected beforehand.

Pupils were quite comfortable with using the software and equipment. In the beginning they asked a lot of questions and demanded explanations on how to do things. Because of limited answers from the teacher (partly on purpose, partly because there were too many pupils asking questions at the same time), they tried out the hard- and software themselves. In quite a short time, they could already find useful tools and commands on their own. They were able to make changes in measurement settings or in the graphical format to fulfill their intentions. During the last classroom meetings, some pupils could set up the whole equipment by themselves.

Pupils' and Teacher's Difficulties in the Activities

In the open-ended post-questionnaire results, the pupils reported mostly technical problems. They had difficulties with the motion detector, the software, and the computers. These were revealed in many different ways by pupils, e.g., "not reaching the furthest distance", "not working", "not measuring" (for the UMD), and "malfunctioning", "broken", "not satisfactory", "out of date", "not saving well" (for the computers). Another problem mentioned by pupils was the lack of space to work on the practical tasks. Concerning the RME approach, some pupils mentioned difficulties in preparing and conducting the presentation and in the cooperation within the group.

The teacher's difficulties were also mostly related to technical issues such as mastering the software in time and his knowledge limitation in technical matters. This was revealed during the post-interview:

My difficulty was, first, because this software is new for me, so I myself also needed a lot of time to master it, in order that instructing pupils can be more convenient. Then, (pause) second difficulty, (pause) if there was an error happened to the computer system, which sometimes we don't understand why it happened (pause) yeah, it was a difficulty. Then, another difficulty, during the practical session, the limited motion space, so that pupils repeated and repeated many times, eventually had to wait in a queue (pause) and even collided with each other here and there (pause). That was part of my problems.

According to the teacher, he did not have problems in conducting the discussions in the introductory activities or during the pupils' presentation. The problems in the first lesson were mainly because the material was new for him and for the pupils, so that sometimes the explanation and communication during introductory activities did not run smoothly. Another problem that he mentioned was

about encouraging pupils' collaboration during group work. When asked about this matter, he stated:

There was difficulty, because there were some of our pupils with such kind of characterization (pause) so that a couple of times I had to (pause) scream, even talked harshly to them to always cooperate and help each other.

Pupil Performance

Pupils' performances were evaluated by their results on the pre- and post-tests, their report on the practical works, and by the teacher's judgement.

Table 2
Pre- and Post-Tests Results

Question No.	1	2	3	4	5	6	7	8
Pre-test Mean	42	64	21	23	34	54	3	43
Post-test Mean	61	70	61	38	69	69	23	63

In general, pupils showed good progress on the post-test. Table 2 shows that the mean value for each question's mark increased between the pre- and post-test. This means that in the post-test session more pupils gave more satisfactory answers to the questions. Not only could they give more correct answers, but they also could reason better in their answers. The mean value of scores of each individual increased from pre-test to post-test up to an increase of 40%. A comparison of the pre- and post-test results also revealed that pupils who got lower marks on the pre-test made greater progress in their post-test scores compared to their fellow pupils who got higher marks on the pre-test.

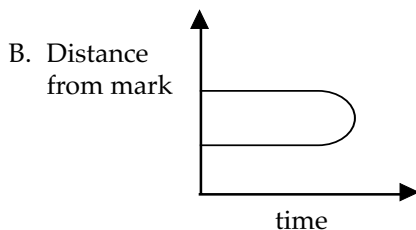
The pre- and post-test results indicate that pupils made progress mostly on items that were related to the distance-time graph (numbers 3, 5, 6) and to the graph with a similar conception in a different context (number 8). In particular, pupils showed more

confidence in giving reasons for their answers. They were more to the point and clearer in stating their explanations, not circling around giving unclear and confusing reasons. Apparent improvements dealt with the graph as picture error that many pupils revealed on the pre-test and with the correspondence between a zero slope in the distance-time graph and cease in motion. These misconceptions did not show up in the post-test anymore. This increase of performance in pre- and post-test is illustrated by two examples:

In question 3 in the pre-test, pupils were given a description of motion:

Adit walks away from a mark on the floor at a steady rate and then directly walks back toward it.

Some options of graphs were given and pupils were asked to answer and give their reason for each graph whether or not it could describe the motion. One of the options was:



Kendy's answer and reasoning for the particular item in the pre-test:

Wrong, because the graph displays that Adit from where he started was back by turning around but not going back on the same path.

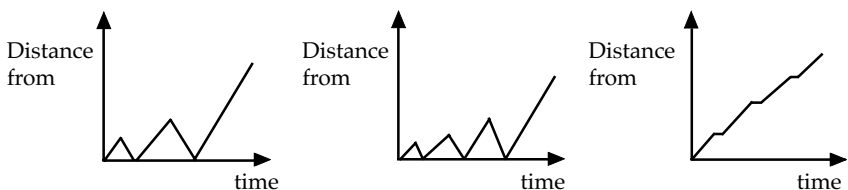
Kendy's reasoning for the associated question and option in the post-test:

Impossible, because in the graph, the time goes back. It is impossible that the time is repeated or back and a person cannot be at a different place or distance at the same time.

In question 5 in the pre-test, pupils were given a description of trips done by three people and six options of the graphs. One of the persons (Valentina) described her trip by:

I take the train every day to go to school. On the way, the train stops twice.

Stefanus assigned option B for Valentina's graph (graph on the left).



His reason was:

Valentina, because it stops twice.

The associated question in the post-test was a trip description made by a person. Victor:

I take the bus every day to school. There are three bus stops on the way.

Stefanus' answer for the associated option (graph in the middle) in the post-test:

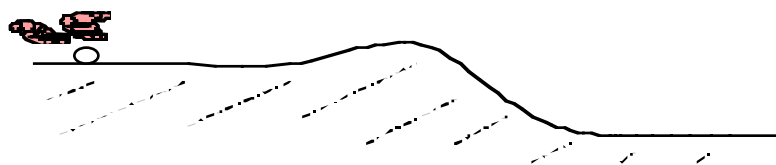
Wrong, because in this graph, it's back to initial place three times with constant velocity.

He assigned the correct graph for Victor instead (graph on the right) and gave reason:

Victor, because there are three flat lines which means he stopped.

Pupils still revealed difficulties dealing with velocity, either in determining velocity from a distance-time graph or in interpreting a velocity-time graph (Questions 4 and 7 in the pre- and post-tests). The teacher also mentioned this in the post-interview. This came to no surprise: pupils were only asked in Practical Work 3 to determine a velocity from a distance-time graph. Nowhere else in the teaching and learning activity were they asked to derive a velocity-time graph from a distance-time graph (it was just implicitly done in some of the practical works). Velocity-time graphs were not covered in the textbook, either. So, the limited discussion of this topic during the classroom activities was clearly not enough for pupils to fully understand the concept. This is also supported by the fact that there were pupils who showed confusion between the distance-time and velocity-time graphs in the post-test. This could well be because they dealt mostly with distance-time graphs during the teaching and learning activity. So they mixed them up, especially in certain features of graphs. To describe this confusion, consider question 4 in the post-test (see Figure 2).

A ball was rolled by somebody on a flat surface. It moved along the surface, went up a small bump and finally glided down. See the picture below:



Which graph best describes the speed of the ball? Explain your reason (for instance why you chose or do not chose a certain graph).

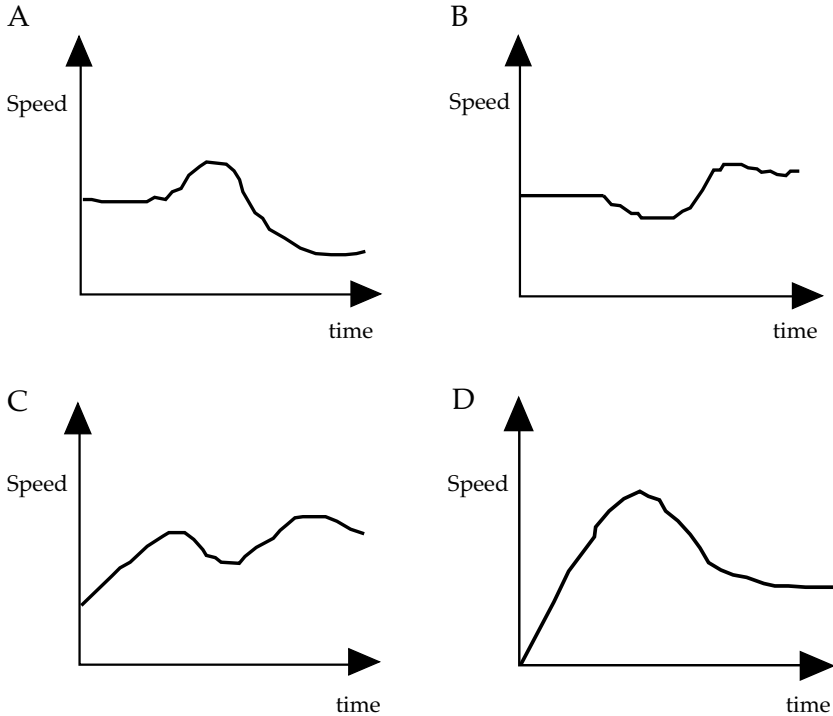


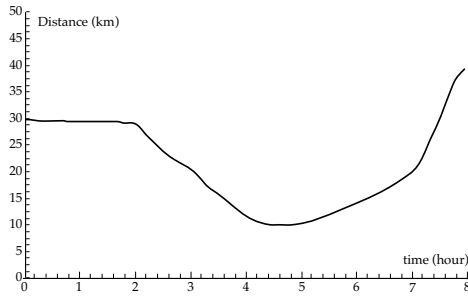
Figure 2: Question 4 in the Post-test

Olivia's answers for option A and B were:

Wrong, because there is a flat line which shows that the ball stopped.

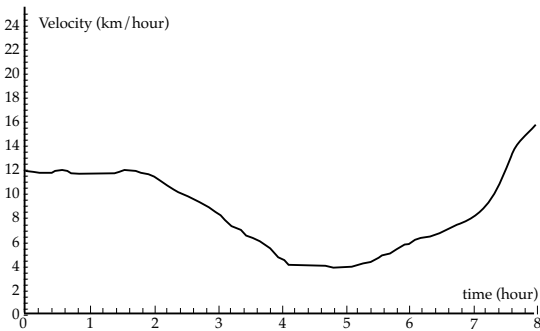
Nevertheless, there was still progress in pupils' reasoning when dealing with a velocity-time graph. Remarkable progress on the item concerning the transformation of a given distance-time graph to a velocity-time graph (see related question from the post-test in Figure 3) was shown by Shanty, as described below.

Below is a distance – time graph of a trip.

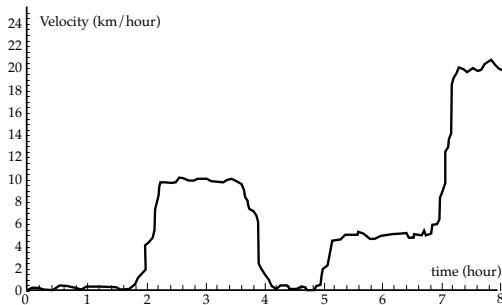


Which of the four graphs below most likely represents the velocity - time graph of the trip? Explain your reason!

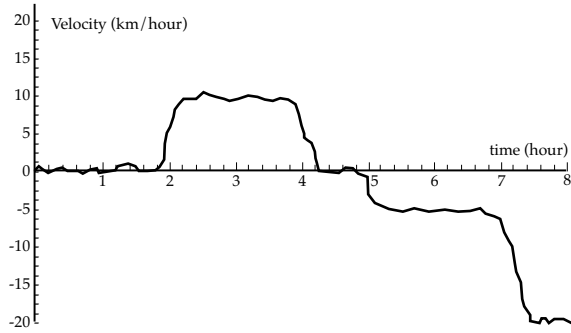
A



B.



C.



D.

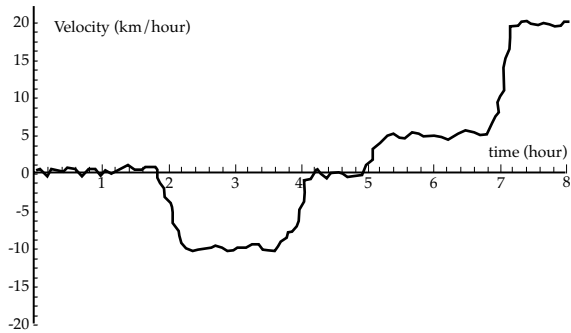


Figure 3: Question about graph transformation in the post-test.

Shanty's answer and reasoning for each option of question 7 in the pre-test:

Option A, B, D: Wrong, because the graph is not suitable with a distance-time graph of a trip.

Option C: True, because the graph is suitable with a distance-time graph of a trip.

Her answer for the associated question in the post-test were:

Option A: Wrong, because in the beginning, the vehicle was not moving in a velocity of 12 km/hour, but it actually stopped.

Option B: Wrong, because the graph shows changing velocity but increasing distance, the distance continuously increased from the initial position.

Option C: Wrong, because the velocity of 10 km/hour should be negative, since the numeral of its final position is smaller than the numeral of its initial position.

Option D: True, because the velocity-time graph shows 2 hours of stop, 2 hours of moving nearer in a velocity of 10 km/hour, then stopped for 1 hour, and moving further for 2 hour in a velocity of 5 km/hour and moving further for 2 hour in a velocity of 20 km/hour. (she also wrote her calculation of the velocities)

This progress was shown not only in the written post-test, but also during the interview with some pupils. For example, Welim suffered with the graph-as-a-picture error and did not reason well during the pre-test. In the post-test however, Welim (W) could interpret the velocity-time graph in question 4 (see Figure 2) correctly

and he could reason meaningfully, as shown in the discussion with the first author (Y) below.

Y: *Which one is correct?*

W: *B*

Y: *B? And the reason?*

W: *Yeah, at first the surface was flat, it moved fast. After that ascending (pause) it ascended then (pause) it was a bit slow, wasn't it? Nah, a bit slow means a bit down (pointing at the part where the graph descends). Then, the ball descended (pause) descended (pause) nah, descending means fast (pointing at the part where the graph ascends). After descending, the surface is flat again, yeah ... a bit normal again.*

Y: *Why didn't you choose C?*

W: *(he thought and mumbled for a while). Eh, C (pause) in C the first motion was directly fast. Here (pointing at the picture in the question) it was not fast, was it? First it should be normal. Here it's suddenly fast. After moving fast, then slow, and then fast again. It was not the case, was it? In my opinion, the velocity is the same. So (pause) not directly fast.*

Y: *If, for instance, when rolling the ball, I pushed it like this? (I made a gesture of pushing with my palm)*

W: *Yeah, that is C.*

Y: *So, that is now C. Why didn't you choose A and B, either ?*

W: *Ehm ... firstly, A here (pointing at the part where the graph ascends) is bulging. When it bulges, it means faster, doesn't it? It should be slower, though. And B here (pause) it is suddenly fast (pause) drastically fast.*

In general, pupils' answers to questions in the practical works were as expected. Some groups seemed to be imprecise when answering questions although they actually could have done better

on this. For instance, pupils were often imprecise when doing point reading. Another prominent point was the use of improper terms in answers. For instance, one group stated, "when walking fast, the graph yields a sloppy line 45 degrees up, and when walking slowly, the graph yields a sloppy line less than 45 degrees." Some groups described intersection as: "crossing like a multiplication sign," "yielding the letter X," "meeting each other." This may be due to the fact that pupils lacked guidance from teacher when doing group discussions.

According to the teacher, the performance difference between pupils taught by this method and the traditional method was not really sharp. However, he admitted that the difference might be greater if the approach was applied to more complicated contextual problems. He believed that those pupils who had the opportunity to apply the topic to practical problems must have more experience in solving them, compared to pupils who only imagined and solved paper and pencil exercises. The teacher also mentioned the fact that in the school's final assessment, the pupils involved in this research outscored those in the other class who he had taught the same topic in the traditional way and who he considered to be stronger in mathematics. This is an interesting side outcome, despite the fact that we could not validate it in this research.

Pupils' Opinions on RME-Based and MBL-Supported Activities

It seemed that pupils of this age enjoy very much being able to carry out experiments during lessons instead of just listening to the teacher and solving written exercises in the classroom. This could be seen from their involvement and their willingness to try out new things during the practical works. On the one hand it resulted in a messy and noisy classroom, but on the other hand everyone seemed to enjoy the work. The teacher supported this view and said that

the pupils tended to follow the lessons more enthusiastically and that they were not easily bored. The classroom work seemed to interest them more.

Pupils' expectations about the teaching and learning activity in general tended to be positive. As much as 61% of the pupils had positive or very positive opinions about RME aspects, only 14% were negative or very negative beforehand. This positive tendency was seen in almost every item, except the ones concerning the presentation of one's work. It seems that many pupils did not think that doing a presentation would improve their understanding. They did not feel ready for the presentation and feared that they might face difficulties. Most pupils' opinions about the usage of ICT in the lessons were positive beforehand, too (54% of pupils). However, somehow they were not really sure whether they would have problems with the software and the equipment, or not.

After the classroom meetings, it seemed that fewer pupils (47%) had positive opinions about the RME approach. Among all items related to RME, pupils still did not seem to think that the presentation encouraged them to understand the material thoroughly and more deeply, and they seemed to think that the tasks and the workload might not have been divided fairly amongst group members.

On the other hand, pupils were still positive about the ICT usage. This was especially shown by the fact that 77% agreed or strongly agreed that doing activities using a computer in the lesson was interesting and exciting, and that 73% of them looked forward to more use of ICT in the next mathematics lessons.

In the analysis of individual pupils, they generally tended to be positive before the classroom meetings, but their opinions afterwards were more variable and had mostly moved towards the less positive. This might be due to difficulties they faced during their work: further analysis revealed that pupils whose opinions

afterwards were less positive than before were the ones who had suffered from many problems and troubles in doing their tasks. Another reason might be that the expectations of some pupils were too high in the beginning and just became more realistic afterwards.

The Teacher's Opinion

During the post-interview, the teacher revealed his opinions about the teaching and learning process in ICT-supported and RME-based activities and about his new role. In general, the tone of the interview was positive. The instructional unit had made a good impression on the teacher, in the sense that he liked his new role and would like to have more teaching and learning activities designed in this way.

According to the teacher, the chosen approach offers both parties (teacher and pupils) advantages. Pupils obtain results more by their own efforts. They experience the process of achieving results by themselves, instead of receiving descriptive materials from the teacher. Moreover, pupils become acquainted with new technology, which is an advantage for them. Their abilities and skills are explored and encouraged more in an open computer-learning environment. They are also trained in doing presentations, speaking in front of an audience, and so on. For the teacher it is an advantage that he or she does not have to spend too much energy on explaining things all the time. It should be noted that this last comment was tentative. If there are ready materials and a fixed arrangement or scheduling of lessons, the teacher might indeed not face many difficulties, but this would certainly not be the case in every situation. The teacher found that the assessment method was appropriate. It matched his idea that the pupils' capacity should not be measured only by written tests.

DISCUSSION AND RECOMMENDATIONS

This study focussed on the applicability of ICT-supported lessons based on a RME approach in an Indonesian classroom context. In this section we summarize and discuss our findings. This leads to recommendations to teachers who want to apply this approach in their own lessons.

Discussion

Many of the findings obtained from the research experiment were in accordance with what we had expected before. *Interactivity* is the keyword to describe the classroom setting. The classroom became livelier with pupils' experimental work as well as with discussions and debates among the pupils and between the pupils and the teacher. Encouraged by the open computer-learning environment, pupils tried to find out things themselves, talked more actively, and they seemed to become more aware of their own mathematical thinking. Pupils were also more involved and more enthusiastic in doing the lesson work. The experimental set-up encouraged them to explore more phenomena. They made predictions and were quite persistent in proving their hypotheses. We would like to state that one of the most important changes in the RME-based and ICT-supported instructional unit was the way pupils were stimulated to think, to question, and to wonder about phenomena. Given a chance to explore their ideas and to discuss them freely, they became more critical and more involved in the learning process, and they were more *willing* to understand things better. But also unexpected things happened. For example, pupils appeared to be concerned more about their tasks when given more self-responsibility.

The technical problems that occurred were also expected beforehand, including the extra time needed by the teacher to master the software. Only the lack of space was not foreseen. Nevertheless,

pupils' ability to cope with the software and the equipment was quite admirable. On the other hand, pupils did feel that they had problems in collaborating within their own group and in conducting the presentation of their work.

The teacher had fewer difficulties during the lessons than expected. He did not have crucial problems either in adjusting to his new role or in conducting class discussions. He felt comfortable with the different role that he took, with the teaching and learning activities, and with the assessment. This might have been due to his nature and attitude in teaching, which was quite progressive, and the fact that he as a mentor of the class had a good relationship with the pupils. His problem, however, lay more in encouraging good cooperation among pupils during their group work.

Pupils showed progress in their performance between the pre- and the post-tests. On the post-test they could give a greater number of correct answers and they could reason better in their answers. Some concepts were mastered and some alternative conceptions were corrected. The topic related to velocity-time graphs had not been mastered well enough, but this might be due to the lack of discussion concerning this topic in the teaching and learning activities.

Evidence was not sufficient to verify some expectations very strongly. Did the materials and activities help pupils to relate what they had learned to problems in daily life? However, by using real situational contexts such as a bouncing ball, the trip from home to school, and human growth, it is hoped that pupils' realizations of mathematical aspects in daily life were encouraged. Although the results from this research experiment do not reveal great differences in pupils' understanding of the mathematical concepts between the traditional lessons and the RME approach, it is the pupils' learning process that might make a difference in the time ahead. It seems logical to expect that pupils who obtain understanding of a concept

by their own struggle and through their own way-of-thinking process will stay with it much longer than pupils who receive ready lesson materials, formulas, and so on, without going through the process of deriving and manipulating them. It is our strong belief that pupils should not only receive, but also should be given a chance to question and process the information they get. This is one of the corner stones of the RME approach.

The use of the MBL environment also helped pupils to elaborate their ideas to their own satisfaction and at their own pace. It served as an open learning environment in which pupils could do trials and experiments, and test their own hypotheses. All of these would otherwise have been more difficult to realize. The MBL environment also enabled the development of materials using daily problems, which were real and meaningful to pupils, and which encouraged them to realize mathematical aspects in nature and in their daily life. Hence, we can see indications that technology might serve as a catalyst for a realistic approach to mathematics education.

It should be noted that starting with real situations and real data is not at all easy. This might even look more complicated as far as real phenomena are concerned. For instance, the graphs produced in the activities in this research were messier and not as ideal as the ones pupils usually are introduced to in their mathematics textbook. This is something to be taken into consideration by teachers. This is just one of the many things that must be paid attention to when adopting the approach. But most important, *the teacher must be willing to change his/her role in the classroom*. The teacher must allocate the more active parts of the learning activities to pupils and must be able to design materials and activities that can stimulate pupils to think, to dare to draw their own conclusions and to express their opinions about the topics they are learning. A teacher also needs to be prepared in technological literacy – at least in basic technical things. On the other hand, pupils should also be prepared, e.g., for more independent self-responsible learning. The roles of

policymakers in education and of the school's management are not less important. The progressive changes in pupils' and teachers' roles, and in the educational approach, crucially need the support and openness of both policymakers and school management. Provision of facilities and access to technology are also things to be taken into consideration nationwide by schools and the government.

Limitations of the Study and Suggestions for Further Research

One of the limitations in the research experiment was the size of observational data and the lack of comparative data. One experiment in one class is a weak basis for making generalized conclusions.

The problem of lack of space in the computer lab forced the teacher and us to split the class in two for most of the classroom meetings. As a consequence, the teacher was not always present during all practical works. This and also the changes to some parts of the lesson design caused weakening of some characteristics of RME that were actually supposed to be a highlight, i.e., *the guided discussions*.

In further research concerning RME-based materials and also in the implementation of an RME-based lesson, this matter should be given more attention. In retrospect, we would like to pay more attention in the learning materials to understanding velocity-time graphs and to transformations from a distance-time graph to a velocity-time graph and vice versa.

Another limitation is the fact that the school was not representative of Indonesian schools in general. At the moment, most schools do not have their own computer laboratories and other sophisticated facilities. Pupils' and teachers' familiarity with technology is also not something that can be presupposed for Indonesian pupils and teachers in general. Further research done

in this area would be very useful if it involved more representative Indonesian schools and also teacher training faculties. Development of materials in other topics that use the RME approach and that are supported by ICT also must be considered.

There were some questions still left to be explored, to which the limited data gained in this research and the restricted time have obscured finding answers to them. One of them is the indication that low achievement pupils might benefit more than high achievement pupils (see the section on pupils' performance). Pupils' and the teacher's changing roles would also have been interesting research topic and could have been given more attention. The concepts of distance and velocity might also be addressed more in further research. Distance and velocity are known to be difficult concepts for pupils, and more attention to these concepts would have been valuable to them.

Recommendation for Teachers

The authors' research experiment leads them to the following list of recommendations for teachers who want to implement RME-based and ICT-supported lessons:

- In general, teachers must be willing to change their role in the classroom towards more pupil-centered learning.
- Activities and tasks should be chosen properly and carefully. Completion of tasks should guide pupils to acquire the concepts they are supposed to master. Too few activities might hinder the process, but too many activities might result in bored and exhausted pupils.
- The organizational things should be paid much attention. It is always better to make sure far in advance the availability of laboratories, other facilities, and so on.

- Especially from the implementation of our instructional unit, we can learn that it is useful to prepare enough laboratory space for pupils to do their practical works, for instance, by a good set up of the laboratory or a good arrangement of groups.
- Teachers should sharpen their skills in conducting class discussions, and in addressing questions that challenge pupils and encourage them to think critically. This might need some practice, training, and customization of teachers' behavior.

FINAL REMARKS

From what happened during the research experiment in an Indonesian classroom, it seems that in practice many things still have to be worked out. It was still difficult, in this case especially for pupils, to adjust to the pupils' more active role in learning. We suppose that encouraging pupils to be more active will be even more difficult in a typical Indonesian school, less progressive than the one involved in the research. It will be more difficult, as well, to change traditional-minded teachers' attitudes. But, this surely can be done. Some Indonesian mathematics educators have already begun such efforts by conducting research, by introducing the RME idea at every opportunity, and by influencing policymakers in education. Developing the idea within teacher training institutes, providing more material for teachers, and establishing good networks among teachers, student teachers, and teacher educators are also efforts in progress.

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