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DEVELOPING STUDENTS' SPATIAL ABILITY THROUGH SPATIAL VISUALISATION AND SPATIAL ORIENTATION TASKS

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Abstract

Spatial ability is an important skill that student need to have. Educators need to recognize that acquiring a range of spatial skills is important for all pupils or students; both for their educational or occupational success and for their everyday competence. Skills such as estimating, geometry, measurement, map-reading and simple drawing are some of the mathematics ideas behind this topic. Considering the importance of this aspect, the development of students' spatial ability can no longer be ignored. In order to to support the development of students' spatial ability, in present study we design a series of learning activities that is combining the spatial visualisation and spatial orientation tasks. This present study is aimed to develop a local instructional theory in this domain and to support the development of students' spatial ability. Consequently, design research is chosen as an appropriate approach for achieving the research aim. In addition, Pendidikan Matematika Realistik Indonesia (PMRI) which was adapted from Realistic Mathematics Education (RME) was deliberately chosen as the approach in the teaching-learning process in the classroom. To conjecture what will happen in the classroom, the Hypothetical Leaning Trajectory was designed which consists of mathematical goals, starting points, mathematical activities, and the hypothetical paths of students' thinking. The research which involved 3 students of 3rd grade of SD Negeri 117 Palembang found that by experiencing working on some spatial visualisation and spatial orientation tasks such as: the activities of constructing the building, drawing, and analyzing two-dimensional shapes, students understand attributes and properties of two-dimensional space and the use of those attributes in solving some spatial problems.

Keywords: *Spatial ability, spatial visualisation, spatial orientation, two-dimensional drawing, three-dimensional drawing*

INTRODUCTION

Spatial ability is an important skill that student need to have (Delice et al., 2009; Revina et al., 2010; Yue, 2006; Walker et al., 2011). As Smith (1992) suggested, educators need to recognize that acquiring a range of spatial skills is important for all pupils or students; both for their educational or occupational success and for their everyday competence. Skills such as estimating, map-reading and simple drawing are some of the mathematics ideas behind this topic (Smith, 1992). To be successful in subjects such as geometry, volume, and measurement students are required to have a good spatial ability. This topic is also one of the competences that are tested in PISA 2003 (PISA framework, 2003).

A lot of research has been done in this domain (Delice, et al., 2009; Revina et al., 2010; Yue, 2006; Walker, et al., 2011; Holzinger & Swineford, 1946; Hegarty & Waller, 2005). Many researchers supported the statement that spatial ability is important to the development of mathematical thinking. Holzinger & Swineford (1946) claimed that spatial ability is closely related to academic achievement, particularly to success in math and geometry. Hegarty & Waller (2005) claimed that in general spatial ability together with intelligence and visual perception is required to develop mathematical thinking. Hegarty & Waller (2005) supported that spatial abilities are important for both constructing and comprehending abstract spatial representations in mathematical problem solving. However, there is still limited research about this domain in Indonesia (Revina et al., 2010). In addition, there is limited research on how the design of learning activities affects the development of students' spatial abilities.

Therefore, more research in this important mathematical domain is needed. In the present study we use the combination of two components of spatial ability, namely spatial visualisation and spatial orientation. These two components are integrated into some tasks to support the development of students' spatial ability.

Since the aim of this study is to help students in 3rd grades of elementary school to develop their spatial ability, we formulate the general research question as: *How can spatial visualisation and spatial orientation tasks support the development of students' spatial ability?*

THEORETICAL FRAMEWORK

Spatial Ability

Spatial ability is defined and evaluated in many ways in the literature. Carol (1993) stated that spatial ability has to do with how individuals deal with material presented in space or more specifically, with a collection of abilities involving imagining, perceiving, remembering, and transforming objects or forms or routes in the real world or through representations of the real world, as in a paper-and-pencil or computer test (Carol, 1993 in Kylllon & Gluck 2003). Hegarty & Waller (2005) and Kozhevnikov, Motes & Hegarty (2007) considered spatial ability as a form of mental activity that enables individuals to create spatial images and to manipulate them in solving various practical and theoretical problems (Pittalis & Christou, 2010).

Lohman (1988, 2000) indicated that spatial ability is composed of 3 separate abilities. These factors contribute the same importance to students' spatial abilities. He defined these three factors as follows:

1. Spatial visualisation is the ability to comprehend imaginary movement in a three-dimensional space or the ability to manipulate objects in the imagination
2. Spatial orientation is the ability of students to remain unconfused by the changing orientation, in which a spatial configuration may be represented.
3. Spatial relation is defined as the ability to mentally rotate a spatial object as a whole fast and correctly.

In this research we used the definition given by Lohman (1988, 2000).

Many researches have been done in this domain. Pitta-Pantazi & Christou (2010) investigated the relation of students' spatial and object visualisation with their creative and practical abilities in three-dimensional geometry. The result suggested that preferences and experiences in spatial visualisation significantly related to students' practical abilities in three-dimensional arrays of cubes. Pittalis & Christou (2010) did a research that involved students in grade 5 to 9. The research finding claimed that spatial abilities constitute a strong predictor of students' performance in the four types of reasoning in 3D geometry. This research's findings suggested that an improvement of students' spatial abilities might result in an improvement of their 3D geometry thinking. Battista (1990) indicated spatial ability as one of the factors that affect success in geometry and geometric problem solving.

Many researchers supported the statement that spatial ability is important to the development of mathematical thinking. Holzinger & Swineford (1946) claimed that spatial ability is closely related to academic achievement, particularly to success in math and geometry. Hegarty & Waller (2005) claimed that in general spatial ability together with intelligence and visual perception is required to develop mathematical thinking. Hegarty & Waller (2005) supported that spatial abilities are important for both constructing and comprehending abstract spatial representations in mathematical problem solving.

Regarding to these facts, develop students 'spatial ability is a must. In fact, as Smith (1992) claimed in her article is that development of students' ability in this skill is still in lack of attention because the system of our education is more centred on verbal and numerical ability. There is also still limited research about this domain in Indonesia (Revina et al., 2010). In addition, there is limited research on how the design of learning activities affects the development of students' spatial abilities. A recent study focused on this topic is the research conducted by Revina et al. (2010) which focus on volume measurement.

Although Revina et al. (2010) in her study claimed that spatial visualisation tasks help students to develop their conceptual understanding of volume measurement; those activities did not fully facilitate the development of students' spatial ability in much broader understanding. As a matter of fact, the research was more centred on spatial visualisation tasks. In fact, there are some other important components of spatial skills that also play a big role in developing students' spatial ability, namely spatial orientation and spatial rotation.

Considering the importance of this domain and in order to fill the gap, a study based on PMRI principles is designed. In this study we use the combination of two components of spatial ability, namely spatial visualisation and spatial orientation. These two components are integrated into some tasks to support the development of students' spatial ability.

Spatial ability in Indonesian curriculum

In Indonesian National Curriculum, there is no specific competence for developing students' spatial ability. The topics that are presented in this research is considered out of curriculum. The spatial abilities that students' develop in these activities are important to support the students' understanding in the chapter of geometry. As a matter of fact, recently in the mathematics textbooks for children in the first and second grade that are published by Pendidikan Matematika Realistik Indonesia (PMRI) foundation, some tasks related to this topic are presented. It indicates that this is an important topic that we should concern about.

The present study

This article is a part of a big research which is conducted in two cycles, namely pilot experiment and teaching experiment. The data presented and discussed in this article is taken from the pilot experiment. Pendidikan Matematika Realistik Indonesia (PMRI) is deliberately choosen as an approach in designing the learning sequence. PMRI is an approach in learning mathematics that is adapted from the Realistic Mathematic Education (RME). The focus on this study is to determine how the activities developed in this study support the development of students' spatial abilities. To be precise, in this article we will describe the development of students' spatial abilities while experiencing working on spatial visualisation and spatial orientation tasks. Thus, we address the following research question: *How can spatial visualisation and spatial orientation tasks support the development of students' spatial ability?*

Data Collection and Method of Analysis

Research Method

In this study we developed six different activities which are integrated and support each other. The first activity supports the second activity; the second activity supports the third activity, and so on, for which each activity have a specific main goal. Since the product of this study is a design of learning activities and the aim of this study is to develop the local instructional theory, design research is deliberately chosen as an appropriate approach. In essence, the interest lay more in finding out how an activity worked than in merely establishing that it worked (Freudenthal (1991) in van Nes & van Eerde, 2010).

Sample

This study involved three students of 3rd grade (ranging in age 9 years) in SD Negeri 117 Palembang, Indonesia. Those students are Pinka, Siti, and Syahrul. The three students comprising the sample for this investigation are quite diverse in level of achievement. Pinka is one of the students who have a high level achievement in their class; she has a very good logical reasoning. Siti is the representation of students with middle level achievement; she can solve the problems faster but sometimes also very careless. Syahrul is the representation of the lower level achievement students; he is the slower one but has a deep analysis.

Data Collection and Method of Analysis

Since the aim of this study is to get a clear description about how the spatial visualisation and spatial orientation tasks support the development of students' spatial ability, all data collected will be analysed qualitatively. The analysis of data collected in this study will be related to the initial HLT. A combination of students' written work, videotaping, audio recording, unstructured students interview, and field notes, help us in analysing and interpreting the data.

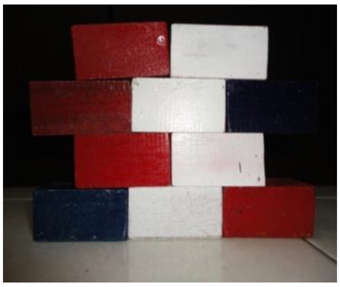
We design 6 series of activities that is validated by five experts in designing learning materials and teaching. In this article we will only discuss three last activities of the complete HLT. The role of the researcher was to teach, to stand by and ask the children additional questions, to help coordinate the activity, to take field notes, to videotape the lesson and to make last-minute changes to the activity in case that seemed necessary for providing relevant information for the research. Before experiencing learning in the series of activity, we conducted a pre-test. The pre-test is aimed to identify students' preliminary knowledge. The pre-test result will be analysed to make sure that those students fulfil the ideal criteria for this series of activities. In the end of the learning sequence, we conduct a post-test. In order to know to what extend the students' development occur, the result of post-test will be compared to the result of pre-test.

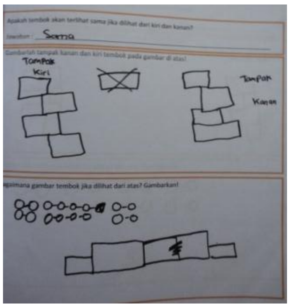
All series of activities done during the preliminary experiment are audio taped and video recorded. During the learning activities, we made some notes about some interesting or important remarks. After experiencing an activity we conducted unstructured students interview about what work and what do not work, why the students react on such ways. We also discussed with the teacher about why students react in a certain way. Those collections of information help us in interpreting and enable us to make data triangulation.

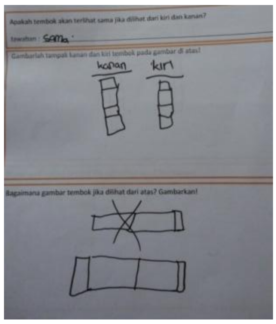
RESULTS AND DISCUSSION

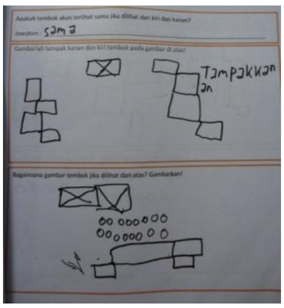
In this study, we design 6 activities. In first third activities, the student work more informal level in which the students work on the Lego® blocks constructed as miniature of an island. In this part, we will discuss the last three activities which were developed on the HLT. In this last activity, students work on regular shape namely blocks and cubes. We choose these three activities because in these last three activities the students working the more abstract level. Furthermore, from this activity we can more elaborate students' thinking, to be précised how students in this age see and discuss about top view and side view.

Exploring the wall

(a) 

(b) 

(c) 

(d) 

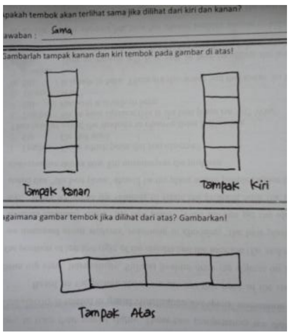
(e) 

Figure 1. The students' answers on the first problem: (a) The picture of the wall (b) Pinka's answers (c) Siti's answers (d) Syahrul's answers (e) The correct drawing

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The goal of this activity is to introduce the spatial terms such as left view, right view, front view, and back view. In this activity, students are asked to solve three problems in which they have to draw the side views and the top view of the wall. The learning activity is started by discussing the side views and the top view of the wall that is used in the last two activities. By the time the pictures of side views and top view of the wall are showed to the students, the teacher started to introduce those spatial terms. Figure 3 show how the students solve the first problem.

From those students' answers we can see how varies their answer. In figure 3 we can see how Pinka, Siti, and Syahrul interpret the drawing of the wall. As we conjectured, none of the students come up with the expected drawing (see figure 3.e) Siti's answers is out of the conjecture, we did not expect that the students will come up with this drawing. Siti drew the left view and right view of the wall as rectangle and square (see figure 3.c). In the discussion session we know that the rectangles represent the goes-in part of the wall and the squares represent the goes-out part of the wall. The learning activity is continued by discussion session. In this session, we showed the students the pictures of the top view and the side views of the walls. The students were asked to analyze each picture given and then drew the side views and the top view. After experiencing this activity, the students start to use navigational term (such as front, back, left and right) in their reasoning, and they start to use the spatial terms such front view, back view, left view, right view, and top view.

The adventure in cube houses

In this activity, students were given some wooden cubes and then asked to construct a cube building/cube house from a certain number of wooden cubes. After that, the students have to draw the side views (left view, right view, front view, and back view) and the top view of the cube houses. The students were given three problems: problem 1 is constructing the cubes house as shown in the picture; problem 2 is constructing a cube house made of 5 wooden cubes, problem 3 is constructing a cube house made of 4 wooden cubes. The figure 4 shows students' work on problem 1.

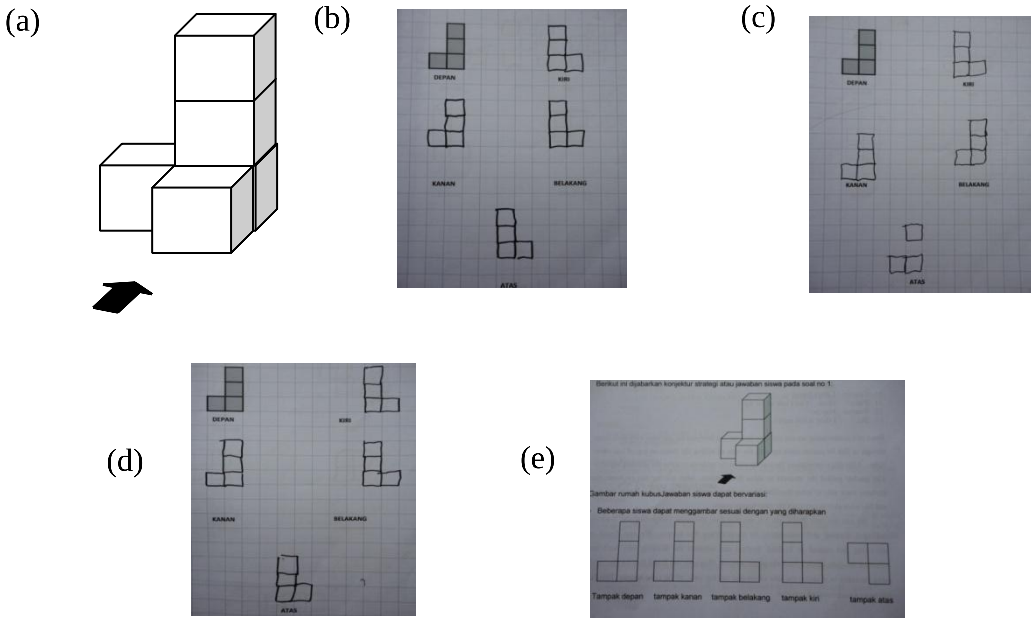

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Figure 4. The students' answers on the first problem: (a) The picture of the cube house (b) Pinka's answers (c) Siti's answers (d) Syahrul's answers (e) The correct drawing

We found that the students did not find any difficulties in identifying the side views of the cube house. The students were able to draw it and can reason why they draw in that way. They were also able to reason the goes-in and goes-out part of the cube house. We are aware that it probably happened because of the example given. Even though the students stated that they used their experience in the fourth activity, we aware that the example may contribute on the way students drew the side views of the cube house. Although the students can draw the side views in a correct way, we found that the students cannot draw the top view of the cube house correctly. Syahrul and Pinka drew the side view of the cube house as the top view of the cube house. Meanwhile Siti drew two squares and a separated square. When the students were asked why they drew it in such way, they only said "I don't have any idea" and "it is difficult". The students cannot relate their experience in drawing the top view on the previous activity in solving this problem. Once the teacher show the top view picture of the cube house the students then can draw the top view of any cube houses.

After experiencing this activity, the students can construct a cube house from a three-dimensional drawing given. It means that the students are able to interpret a three-dimensional drawing. The fact that the students are able to draw the side views and top view of the cube house indicates that the students are able to draw and to reason their drawing. In conclusion, after experiencing this activity the students start to develop their ability in drawing, interpreting, and reasoning two-dimensional drawing of a three-dimensional object.

Finding the treasure

In this activity students were asked to draw the side views and the top view of the cube house, in this activity students were asked to construct a cube building from three given views. This activity is quite difficult for the students. Pinka, Siti and Syahrul were struggling in solving this problem. They took longer time than we expected. Those students started constructing the cube house by considering different view. Pinka started constructing the cube building from the left view, Siti started from the front view, meanwhile Syahrul started from the top view. Siti constructed two different cubes houses. One of the cube houses is made based on the front and the other one is made based on the left view drawing. Pinka tried to construct the cubes house by combining the drawings given. Pinka seemed did not understand what the layers represent on the left and the front view drawings. In the beginning we expect that she will construct the cube house by adding cubes on top of the cubes which is arranged based on the top view (top view-cubes). In fact, instead of adding on top of the top view-cubes, she added in the left and right of the top view-cubes. Pinka kept doing it until Syahrul criticized her work.

1. Syahrul : You should not do that.
2. Pinka : So, how should I do? Tell me if you can do it.
3. Syahrul : You may not add in this side (pointing the area out of the top view-cubes). You will break the top view.

4. Pinka : So, where can I add the cubes then? How can I construct the front and left view?
5. Syahrul : I don't know. But, I am sure that you may not add on this side. (pointing the area out of the top view-cubes).
6. Pinka : Hmm…
7. Teacher : Do you agree with him Pinka?
8. Pinka : Somehow. But, where can I add the cubes then, miss?
9. Syahrul : Anywhere! Except this side, isn't it? Pointing the area out of the top view-cubes).
10. Teacher : I don't know!
11. Pinka : Hmm… *Can I add on the top?!*
12. Teacher : May be!
13. Siti : I think it will work!

From this conversation we can see how Syahrul can interpret the top view very well, even though in fact he cannot come up with the idea of adding the cubes on top of top view-cubes. After this conversation, the teacher asked the students to solve the problem together. The teacher guided the students to solve this problem. After solving this problem, the students were able to solve the other two problems in short period of time. We found that Pinka, Syahrul and Siti were able to construct the cube houses easily.

We can see how Pinka and Siti develop their ability in interpreting the drawing, making a drawing and constructing by experiencing this activity. We also found an interesting fact related to Syahrul. Syahrul can interpret the drawing very well and construct the cube houses from the given pictures. However, we found that he frequently make mistakes in drawing the side views and the top view of the cube houses. This fact leaves us an unanswered question.

Pre-test and Post-test

The pre-test was conducted in the beginning of learning activities which is aimed to know students' preliminary knowledge. Meanwhile the post-test which is aimed to measure students' development was conducted in the end of learning activities. Since it brings two different aims, we designed different questions for the pre-test and post-test. However, there is also a part in the pre-test and post-test which have same questions. Based on the pre-test and post-test result, we found that after experiencing this series of activity the strategies used by the students in solving the problems are progressed. We also found that the students are also able to reason and read a three-dimensional representation of three-dimensional object.

CONCLUSION

Before elaborating a general conclusion of this paper, it should noticed that this study is a part of an exploratory design research. Hence, the conclusion that will be addressed in this paper is in limited setting and scope. Limited settings really affect the result of this study. The fact that this study was conducted in the teacher office created some problems in teaching experiment and analyzing the result. A lot of noisy and some interruption by the teachers and other students during the learning activities create a non-conducive learning environment. We found that the unsupported learning environment really affect the students concentration in learning.

After experiencing this series of activity, the students can read, interpret and count the three-dimensional drawing of cubes houses. This finding supports the result of Pittalis & Christou (2010) study which suggested that preferences and experiences in spatial visualisation significantly related to students' practical abilities in three-dimensional arrays of cubes. Therefore, teacher may use these instruction activities to support students who still have difficulties in read, interpret and count the three-dimensional drawing of cubes arrays.

How can spatial visualisation and spatial orientation tasks support the development of students' spatial ability?

In this research we found that: 1) Soon when students experience the Exploring the structure of the wall, they started to develop their navigation idea such as front, left, right, back, and top. 2) The strategy used by the students in indicating the top view of the objects was gradually progressed; in the first time, they really need to see the object from the top, once they get the idea of the top view, to draw the top view of the object they just see the object from the bird eye view. 3) The last two activities; namely the adventure in the cube house and finding the treasure help the students in reading, interpreting, and reasoning two dimensional drawing.

Concerning the findings of this research, we conclude that by experiencing working on some spatial visualisation and spatial orientation tasks such as: the activities of constructing the building, drawing, and analyzing two-dimensional shapes, students understand attributes and properties of two-dimensional space and the use of those attributes in solving some spatial problems.

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