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Virtual Mathematics Kits (VMK): The Value of Spatial Orientation on It

Lingga Nico Pradana
Universitas Negeri Malang, INDONESIA

Cholis Sa'dijah*
Universitas Negeri Malang, INDONESIA

I Made Sulandra
Universitas Negeri Malang, INDONESIA

Sudirman
Universitas Negeri Malang, INDONESIA

Octarina Hidayatus Sholikhah
Universitas PGRI Madiun, INDONESIA

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Abstract: The purposes of the current study were to develop students' spatial orientation skills using Virtual Mathematics Kits (VMK) and to evaluate VMK as a form of digital media in terms of spatial orientation. This study involved 42 lower-class and 47 higher-class elementary school students as the intervention group and 36 lower-class and 41 higher-class students as the control group. The intervention group was administered spatial orientation activities for 10 weeks. These activities were performed using a VMK to facilitate solving spatial problems. In the end of activities, spatial orientation instruments administered to compare spatial orientation ability on each group. The findings of this study, spatial orientation activities using a VMK improved students' spatial orientation skills. More specific, VMK provides more significant effect on higher-class students. Finally, VMK allows students to explore many ideas and perspectives to solve various spatial problems. VMK can be used as a digital media that helps students to develop spatial reasoning.

Keywords: *Spatial orientation, virtual mathematics kits, digital media, extracurricular activities.*

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Introduction

The realm of education has entered the digital era. The use of technology in education has become important (Akayuure et al., 2016; Genlott & Gronlund, 2016; National Council of Teachers of Mathematics [NCTM], 2006). However, technology is not yet widely used in elementary school mathematics education. Primary school mathematics education requires analyzing, reasoning, conveying ideas, and solving problems in various situations (Organisation for Economic Co-operation and Development/OECD, 2012). In terms of various factors related to mathematical ability, spatial reasoning is noteworthy. Based on previous studies, spatial reasoning can improve students' mathematical performance (Cheng & Mix, 2014; Lowrie, 2016; Lowrie et al., 2017) and improve capabilities in Science, Technology, Engineering, and Mathematics (STEM) fields (Mulligan et al., 2017; Newcombe, 2013). Therefore, spatial reasoning is very important to science and mathematics, especially in primary education.

Spatial reasoning is the ability to represent and use objects and their relationships in two dimensions or three dimensions (Linn & Petersen, 1985; Williams et al., 2010). This ability involves manipulating, determining patterns, and finding relationships between two-dimensional and three-dimensional objects. Spatial reasoning has several categories. According to Linn & Petersen (1985), spatial reasoning is categorized into spatial visualization, mental rotation, and spatial perception. Additionally, based on primary education curricula, Lowrie et al. (2017) categorized spatial reasoning into spatial visualization, mental rotation, and spatial orientation. In contrast, Yuksel (2017) categorized spatial reasoning into spatial perception, spatial visualization, mental rotation, spatial relations, and spatial orientation. While the categories presented by these experts are not identical, they are complementary.

Previous studies have discussed several categories of spatial reasoning. Some researchers have designed activities aimed to improve students' spatial reasoning (Basham & Kotrlik, 2008; Cheng & Mix, 2014; Hallowell et al., 2015; Lowrie et al., 2017). In one study, activities based on spatial reasoning were carried out outside of mathematics lessons. In other words, these activities were not integrated into mathematics learning. Other researchers measured spatial

* **Corresponding author:**
Cholis Sa'dijah, Universitas Negeri Malang, Department of Mathematics Education, Indonesia. ✉ cholis.sadijah.fmipa@um.ac.id

reasoning and compared it with mathematical performance (Freeman et al., 2014; Hawes et al., 2015; Lowrie et al., 2017; Moss et al., 2015). These studies' results show that the level of mathematical performance is closely related to the level of spatial reasoning. Previous research on spatial reasoning has examined several categories at once. The study discusses more about spatial reasoning than the ability of each spatial reasoning category. In a special cases, spatial visualization and mental rotation researched in elementary school and compared with mathematical abilities (Haciomeroglu, 2016; Hawes et al., 2015), while the spatial orientation has not been explored in detail. The technologies used in training spatial reasoning skills are still not specific to or specifically designed for each category of spatial reasoning. Therefore, research should be done on training specific categories of spatial reasoning.

In spatial reasoning theory, certain categories of spatial reasoning are very likely influenced by other categories (Bruce et al., 2015; Lowrie & Jorgensen, 2017; NCTM, 2006). One of these categories is spatial orientation. Spatial orientation is the ability to enter a given spatial situation (Liao, 2017; Peng & Sollervall, 2014; Pittalis & Christou, 2010). In spatial orientation, individuals are required to realize whether one object is to the right or left of, higher or lower than, or closer than another object. The other categories of visualization, rotation, perception, and relations always involve a spatial situation. This means spatial orientation plays a very important role in spatial reasoning. Moreover, spatial orientation is a very important factor that supports other categories of spatial reasoning.

Based on the above description of spatial reasoning, we designed a form of digital media to improve the spatial orientation skills of elementary school students. We created a Virtual Mathematics Kit (VMK) and used it for spatial orientation activities. A VMK is a collection of software products that present a spatial situation (Pradana et al., 2020). The given spatial situation of a VMK allows students to obtain information from various perspectives. In spatial orientation activities, VMK have three purposes: 1) representing objects and mathematical problems related to spatial reasoning; 2) transforming mathematical concepts into tools that can be manipulated; and 3) helping students create problem-solving ideas. By looking at the advantages of VMK, the purpose of this study was to examine the improving of students' spatial orientation using digital media.

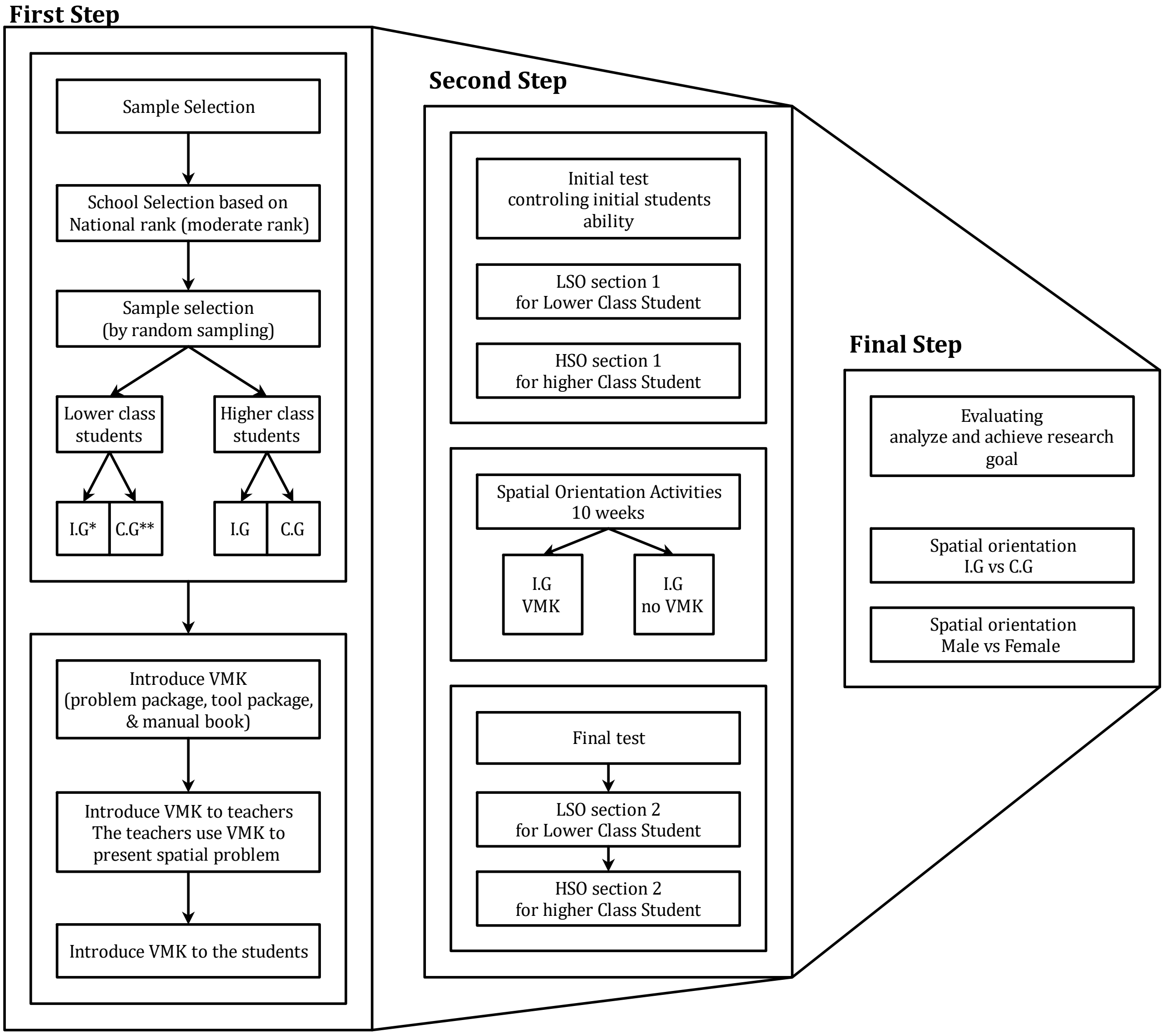
Methodology

Research Goal

The purpose of this study was to examine the improving of students' spatial orientation. More spesific, we compare the ability of students' spatial orientation on both lower class and higher class. Futhermore, we also compare spatial orientation ability by gender (male & female).

Research Design

To achieve the research goal, a quasi-experimental design conducted by carry out extracurricular activities based on spatial orientation content. The extracurricular activities designed by exploring spatial content using VMK as digital media. For the first step, we were conduct sample selection of elementary school students and devide student into two group (intervention and control group). We also introduce the VMK to teachers and students (include manual book of VMK). Second step, the spatial orientation test administered to the student in both groups. This test conducted to control the students' initial spatial orientation ability. Thus the students on both group at least had the same spatial orientation ability. Then, the students take extracurricular activities in 10 weeks. After student finish their activities, the final test conducted to examine students' final spatial orientation ability. On the Final step, we evaluate the result of the test to achieve research goals. The summary of the research design presented on Figure 1.



**I.G : intervention group; **C.G : control group.*

Figure 1. Research Design

Participants

This study involved two subject categories, specifically lower- and higher-class elementary school students. The participant selected by stratified random sampling. Lower- and higher-class were stratification to divide student in two grade categories. Then students from each category were randomly selected as the participant of this study. The participant of this study has following criteria. The lower class included 42 students (23 third grade students & 19 second grade students; mean age = 8.3; age range = 7.9 – 9.1; 17 males & 25 females), while the higher class included 47 students (14 fourth grade students, 14 fifth grade students, &19 sixth grade students; mean age = 11.2; age range = 10.3 – 12.4; 21 males & 26 females). Students were assigned to the intervention group from both the lower and higher classes.

As a comparison, the control group was created with students from both categories. The lower class included 36 students (25 third grade students & 11 second grade students; mean age = 8.6; age range = 7.3 – 9.1; 12 males & 24 females), while the higher class included 41 students (12 fourth grade students, 11 fifth grade students, & 18 sixth grade students; mean age = 11; age range = 9.7 – 12.2; 18 males & 23 females). The summary of student characteristics presented in Table 1.

Table 1. Student Characteristic

Group	Class	N (by Class)	N (by Grade)	Mean Age	Range Age	Male & Female
Intervention	Lower Class	42	23 third grade 19 second grade	8.3	7.9 – 9.1	17M & 25F
	High Class	47	14 fourth grade 14 fifth grade 19 sixth grade	11.2	7.9 – 9.1	21M&26F
Control	Lower Class	36	25 third grade 11 second grade	8.6	7.3 – 9.1	12M & 24F
	High Class	41	12 fourth grade 11 fifth grade 18 sixth grade	11	9.7 – 12.2	18M & 23F

The school was selected based on school rankings for the last 3 years (using national exam data from ministry of education, Indonesia). The chosen school had a moderate ranking (interval of mean $6.705 \leq \bar{X} \leq 7.735$).

Data collection instrument

Two instruments were used to measure the spatial orientation skills of the lower- and higher-class students. Table 2 presents the differences between the two instruments. Both tests were made before the study considering the elementary school education curriculum in Indonesia, especially mathematics learning. The mathematics education curriculum for the lower classes includes shape recognition material and its properties, including angles and symmetry. The curriculum for the lower classes is designed to use more concrete objects as main models. The mathematics curriculum in the higher classes involves building spaces and combining several building spaces, such as determining the volume and surface area of a building and depicting building spaces two-dimensionally. The sample of the instrument present on Figure 2.

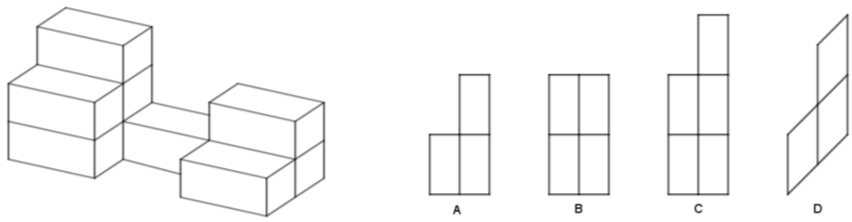


Figure 2. Sample of Test

Table 2. Spatial Orientation Instrument

Spatial Orientation	LSO test	HSO test
• Determine the position of an object • Draw the face of an object relative to the observer • Count objects that are put in a certain place	• Consists of real objects • Shapes • 20 questions • 3 options • 60 minutes	• Consists of real and abstract objects • Shapes and Solids • 30 questions • 4 options • 60 minutes

Considering these matters, the instruments used in this study involved objects that are suitable for both lower and higher classes. Both tests consisted of two sessions, namely section 1 (initial ability) and section 2 (final ability). By using Cronbach's Alpha formula, the reliability scores of LSO test section 1 and section 2 were 0.73 and 0.79, respectively. The reliability scores of HSO test section 1 and section 2 were 0.81 and 0.76, respectively.

LSO and HSO tests were given to all students in the intervention group and the control group. LSO and HSO section 1 tests were administered before extracurricular activities began to discover students' initial spatial orientation skills. The tests occurred 2 weeks before the activities. Then, LSO and HSO section 2 tests were administered 3 weeks after the extracurricular activities to discover students' final spatial orientation skills.

The Use of VMK in Extracurricular Activities

A VMK is a collection of software products used to 1) represent objects and mathematical problems related to spatial reasoning; 2) transform mathematical concepts into tools that can be manipulated; and 3) help students create problem-solving ideas. A VMK was created to help students with extracurricular activities. The software used to create the VMK was Geogebra, Matlab, and Office mix. The sample of VMK present on Figure 3.

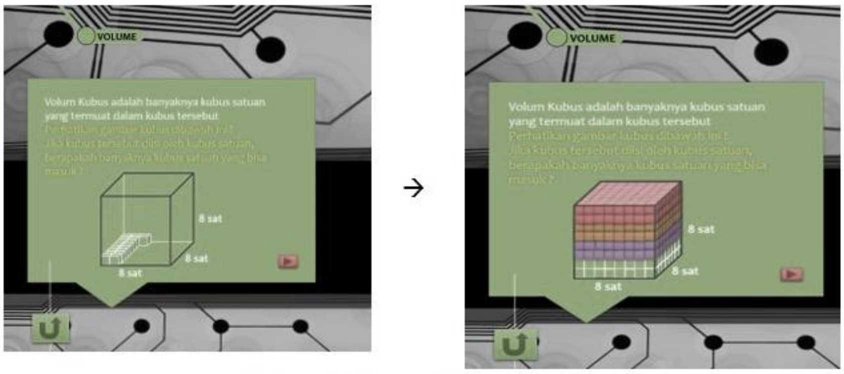


Figure 3. Sample of VMK

In this study, extracurricular activities means mathematics extracurricular activities in the field of geometry aimed to train students' spatial orientation abilities. These spatial orientation abilities were trained using extracurricular activities based on spatial reasoning. The extracurricular activities were held for 10 weeks (90 minutes each week). These activities were: 1) determine the position of an object when observed from various sides; 2) describe the side of an object from an orthogonal view to an isometric view; 3) distinguish reflection and rotation. Activities were designed and adapted for the mathematics curriculum in elementary schools in Indonesia.

During the activities, we collaborated with class teachers. Activities were carried out with a collaborative concept and each group used one VMK package. The VMK only used on intervention group. The teacher's task in this study was as a model teacher who presents spatial problems (using VMK) while the researcher accompanies students using VMK to solve the problems. This task was carried out in the intervention class. The VMK was introduced before the extracurricular activities so that students would be more familiar with it. In the control group, teacher and student were not use the VMK. The spatial problem presented by using spatial object such as cube & cuboid model and paper folding. Thus the different between two group was the form of media used. The intervention group uses digital media (VMK) and the control group uses concrete media.

Data Analysis

The first analysis was carried out to find students' initial spatial orientation skills in the intervention group and the control group. A conservative $\alpha = 0.01$ (p values) was used for One-Way ANOVA analysis. This analysis was also used to determine whether the intervention group and the control group had the same spatial orientation ability. The results of the LSO and HSO section 1 tests were used for this analysis. The second analysis was carried out to find students' final spatial orientation skills in the intervention group and the control group. Two-way ANOVA analysis was conducted to compare mean scores on the LSO and HSO section 2 tests between the intervention group and the control group. We then compared the mean scores on the LSO and HSO section 2 tests by gender (only students participating in extracurricular activities).

Findings / Results

The results of the study are presented in 3 parts. The first part shows the students' spatial orientation before 10 weeks of extracurricular activities (initial ability). The second part shows the mean comparison between the two groups (intervention group and control group) from the results of the LSO and HSO section 2 tests. The third part shows the different mean scores by gender (male and female) for participants in the extracurricular activities. In addition to p values, the effect size is reported. Table 3 presents the means and standard deviations for the lower and higher classes.

Table 3. Means and Standard Deviations of Lower and Higher Classes

Measure	Intervention Group		Control Group	
	M	**SD**	**M**	**SD**
LSO section 1	20.16	6.04	21.84	6.14
LSO section 2	23.47	6.53	23.53	5.06
HSO section 1	34.62	6.97	35.52	7.03
HSO section 2	37.24	7.11	35.74	7.12

Table 4. Compare Means Result of Students' Initial Spatial Orientation Ability

Intervention vs Control	*df*	*F*	*p* (0.01)	Decision
Lower class	(1,77)	4.68	0.27 > *p*	Accept H_0
Higher class	(1,87)	11.48	0.00 < *p*	Reject H_0

Table 5. Compare Means Result of Students' Final Spatial Orientation Ability

Intervention vs Control	*df*	*F*	*p* (0.01)	Decision
Lower class	(1,77)	3.76	0.14	Accept H_0
Higher class	(1,87)	13.28	0.00	Reject H_0

Table 6. Compare Means Result of Gender Test

Intervention group	*df*	*F*	*p* (0.01)	Decision
Male vs Female	(1,87)	4.79	0.00 < *p*	Accept H_0

Students' initial spatial orientation ability

One-way ANOVA was performed to compare the mean scores of the LSO and HSO section 1 tests between the intervention group and the control group. The detail result presented on Table 4. There was no significant difference in mean scores in the lower class: F (1, 77) = 4.68, p = 0.27. Lower-class students' spatial orientation scores were similar. Furthermore, there was a significant difference in mean scores for students' spatial orientation in the lower class: F (1, 87) = 11.48, p< 0.01. Thus, the students' initial spatial orientation scores in the higher class were different. Viewed by mean scores, the control group had better initial ability than the intervention group. This result prompted one question: could VMK in the activities improve higher-class students' spatial orientation?

Students' final spatial orientation ability

Students' final spatial orientation ability was analyzed by two-way ANOVA. The mean scores of LSO and HSO section 2 tests were compared between the intervention group and the control group. The detail of the test presented in Table 5. The lower-class comparison showed no significant difference between the two groups: F (1, 77) = 3.76, p = 0.14. This result means the intervention group had same spatial orientation ability. In the higher class, there was a significant difference between the two groups: F (1, 87) = 13.28, p < 0.01. Based on mean scores, the intervention group had higher scores than the control group. This result shows that the use of VMK for spatial orientation activities improved students' spatial orientation.

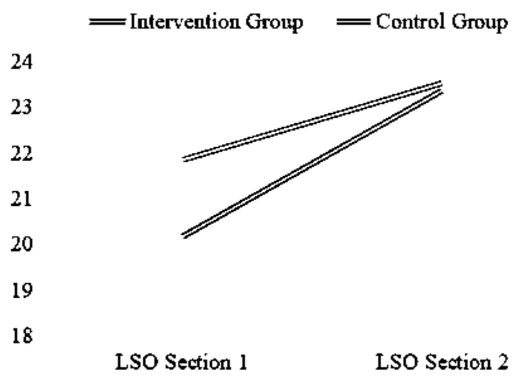


Figure 4. Lower-class Mean Scores on Spatial Orientation Test

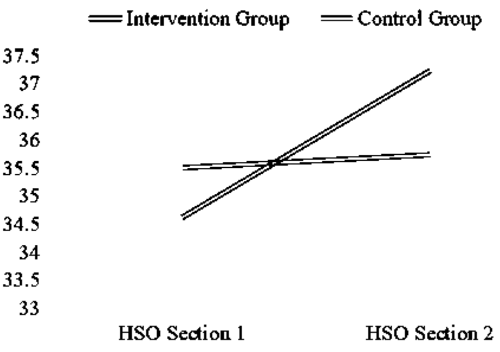


Figure 5. Higher-class Mean Scores on Spatial Orientation Test

Spatial orientation by Gender

We also compared mean scores by gender (38 Male (M = 30.28; SD = 6.97) vs 51 Female (M = 31.67; SD = 6.72)) by the result of two-way ANOVA. This comparison ignored class category and was only carried out for students in the intervention group. The detail of the test presented in Table 6. There was no significant difference between male and female performance on the spatial orientation section 2 test: F (1, 87) = 4.79, p< 0.01. This result shows that males and females have the same performance on spatial orientation activities. Thus, using VMK in spatial orientation activities has the same benefit for both male and female students.

Discussion

This study indicates that digital-based tools can improve spatial orientation ability. Although previous research has already shown the usefulness of spatial tools in mathematics learning (Charalambous et al., 2011; Fischer et al., 2011; Kovacevic, 2017), our study shows that using VMK as a digital tool directly affects spatial ability (in this case, spatial orientation) in early elementary school students from both lower and higher classes. VMK not only have significant effects on mathematical literacy (Pradana & Sholikhah, 2019), but also improves students' spatial orientation in designed activities. Spatial orientation is one of the spatial abilities related to adaptability to spatial situations. Many studies on spatial ability have shown that spatial ability can improve and support students' mathematics performance (Cheng & Mix, 2014; Kospentaris et al., 2016; Lowrie et al., 2017). VMK are an alternative media that can be used by elementary school students. VMK can be effective for students, especially in higher grades.

Viewed by class category, the two groups from the lower class had the same spatial orientation performance. These results are unique, because the spatial orientation activity using VMK had no significant effect on students. In this category, the activity was designed to use real-world content to show many shapes from different perspectives. Thus, students discovered various shapes by identifying the natures of the seen objects. From a spatial orientation perspective, students could determine the position of an object. However, consistency in stating objects' position depends on other objects and requires more time to train. Some students drew the face of an object based on what they saw. Thus, students did not adapt to the given conditions. This activity was really difficult for lower-class students.

The fundamental problem in this category was the time taken. These students needed more time to do this activity because their cognitive development is still in the early stages (Akayuure et al., 2016; Hirza et al., 2014). Although the students were motivated to use the VMK, they still had difficulties using it effectively. As in previous studies, real spatial tools are still the main choice to improve student' spatial reasoning (Alp et al., 2008; Levenson et al., 2010).

For the higher-class students, the results of this study are very interesting. The initial spatial orientation ability of the control group was better than that of the intervention group. However, after 10 weeks of activities, students' spatial orientation ability in the intervention group improved and was better than that of the control group. Students were very enthusiastic about using the VMK in spatial orientation activities. Although this digital media was new to them, students had high interest. Some students had difficulty using the VMK, especially for geometric objects. However, the activity continued smoothly because the teacher and researcher assisted students. VMK let student reason easily. Once again, dynamic objects are very helpful for students in creating problem-solving ideas (Greefrath & Siller, 2018; Guven & Kosa, 2008; Scheltenaar et al., 2015).

Students' needs differ between the lower and higher classes. Lower-class students need to solve real problems. Thus, students have difficulties with mental reasoning tasks. The VMK was designed to easily represent dynamic objects that can be fully manipulated by students during spatial orientation tasks. However, lower-class students had difficulties using the VMK and focusing on the task. Thus, lower-class students must be introduced to VMK in order to easily do tasks. In contrast, higher-grade students easily used the VMK. They collaboratively used the VMK as a tool for solving spatial tasks in activities. Thus, the conclusion is that VMK can be effectively used for higher-class students. For lower-class students, VMK need to be easy to use and students should be introduced to them before use.

Regarding spatial performance by gender, this study found no difference in spatial orientation ability between male and female students. This agrees with previous studies that showed that male and female elementary school students have equal spatial reasoning performance (Gilligan et al., 2017; Patkin & Fadalon, 2013). Even in term of STEM the gender different have a difference (Sagala et al., 2019), this study present no difference in specific field. The activities in this study required students to work together to solve spatial tasks. Therefore, both male and female students could express ideas. This finding is also supported by previous studies on activities that allow students to work together (Ic & Tutak, 2017; Salmah et al., 2015) and the gendering view of elementary student on mathematics (Forgasz & Markovits, 2018).

Conclusion

This study shows that the use of digital media such as VMK can support spatial orientation activities. Students who are involved in spatial orientation activities experience increased spatial orientation skills, especially higher-classes students. Students can learn spatial orientation activities; an important aspect of mathematics is the ability to present abstract concepts in concrete forms. Furthermore, the gender aspect has no effect no spatial orientation ability. That means gender is not a factor that can affect students' spatial orientation abilities especially on this study. Thus, the main factor to improve spatial orientation ability is the use of digital media such as VMK.

Suggestions

VMK can provide forms that are not only concrete, but also dynamic and manipulative. Therefore, in activities based on spatial reasoning, it is highly recommended for teachers to use digital media such as VMK. Furthermore, the future research can examine more deeply the relevance of spatial reasoning to the basic education curriculum. Educators should pay attention to the spatial reasoning of students and improve student' abilities. Moreover, the use of digital technology can aid with primary education learning. Research on digital technology in education could help prepare students to face the industrial revolution 4.0.

Limitations

Extracurricular activities in this study require the ability to use digital media properly. The introduction of digital media (VMK) still needs to be improved so that teachers can utilize it well. The habituation of digital media still needs to be improved both for teachers and students. Thus VMK can provide maximum influence in facilitating students to develop their spatial reasoning abilities.

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