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Research Article

An investigation of mathematical problem-solving skills based on students' prior mathematical knowledge and cognitive style

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Several prior research concluded that students' mathematical problem-solving skills (MPSS) were deemed inadequate. The research necessitated additional research into the components that govern it. This study explored the differences in MPSS between students based on their basic mathematics knowledge and cognitive style. This study was conducted using a survey and quantitative analysis utilizing inferential statistics. Cluster sampling was used to choose 182 students from a junior high school in Bandung, Indonesia. There were 91 male and 91 female pupils in the sample. Valid and reliable mathematical prior knowledge tests, MPSS tests, and the Group Embedded Figure Test (GEFT) were used as data mining instruments in this work. The acquired data were analyzed using JASP software and a two-way ANOVA test. This study found that, first, there is no difference in MPSS based on prior knowledge of mathematics. Second, there are moderate differences in MPSS based on cognitive style. Third, there is no interaction between the effects of prior knowledge of mathematics and cognitive style on MPSS. This study concludes that cognitive style is the most influential factor influencing students' MPSS.

Keywords: Cognitive style, mathematical problem-solving skills, prior mathematical knowledge, two-way ANOVA

1. Introduction

Students are frequently confronted with a variety of challenges in both academic and real-world contexts. Students must be prepared with students' mathematical problem-solving skills [MPSS] if they are to be able to handle challenges that are becoming increasingly complicated. Through this capacity, individuals will comprehend and be able to employ numerous ways to solve mathematical issues (Gavaz et al., 2021; Marchiş, 2013; Phonapichat et al., 2014). MPSS comprises a person's capacity to adapt numerous tactics and strategies from previously learned activities to find the optimal answer to a new problem or situation (Bakar et al., 2021; Schoenfeld, 1982). By teaching MPSS, students can become accustomed to being able and skilful in comprehending the many challenges encountered, developing diverse problem-solving methodologies, and being aware of the necessity of re-examining previously achieved solutions. In light of this urgency, solving mathematical problems is a fundamental component of mathematics curricula in numerous nations (Aydın Güç & Daltaban, 2021; Liljedahl et al., 2016; National Council of Teachers of Mathematics [NCTM], 2000; Peng et al., 2020).

MPSS includes complicated cognitive functions in practice. MPSS is classified as a higher order mathematical thinking skills (Simamora et al., 2018; Sumarmo, 2012). This description illustrates MPSS's strategic stance in math education. However, according to the Program for International Student Assessment [PISA] assessment, conducted every three years since 2009, Indonesia is in the bottom ten regarding mathematical literacy. This PISA research also assesses pupils' problem-solving abilities in mathematics. In fact, according to the 2018 PISA report, the average mathematics score of Indonesian pupils was only 379, and only 1% of them could finish strenuous mathematical exercises (OECD, 2019). These results are consistent with earlier research findings indicating that students struggle to answer questions or complete assignments requiring MPSS (Phonapichat et al., 2014; Sumirattana et al., 2017; Tambychik & Meerah, 2010). Therefore, multiple efforts are required to acquire this talent.

To build MPSS, which is part of high-level mathematical thinking skills, Fraillig et al. (1999), Suryadi (2012), and Suryadi and Herman (2008) recommend three development tactics, including the uncover approach, the push strategy, and then the developing strategy. The capacity of students to solve mathematical problems and the elements that can affect them can be investigated through the discovery of mathematical problem-solving procedures. Such disclosure is required for the design of effective learning in order to assist the growth of MPSS. Notably, in 2020 and 2021, the Covid-19 pandemic caused a decline in kids' mathematical proficiency, or what many experts call learning loss (Kuhfeld et al., 2021, 2022; Kuhfeld & Tarasawa, 2020; Lewis et al., 2021; Patrinos et al., 2022). After the pandemic has subsided, it is vital to disclose MPSS as an effort to assist the development of this capacity through the application of several effective learning methodologies.

In order to support the development of MPSS, it is vital to identify the factors associated with students' mathematical problem-solving success. MPSS is believed to be associated with the mental activity of students. Swanson et al. (2021) explain that mental and cognitive activity plays an important role in mathematical problem-solving. According to Piaget's thesis, cognitive development can occur through assimilation and accommodation (Piaget, 2003). Assimilation is the process of obtaining new knowledge based on existing information. In contrast, accommodation entails adjusting after acquiring new information or knowledge. Therefore, these assimilation and accommodation processes complement one another.

In order to answer a mathematical problem, it is necessary to combine the processes of assimilation and accommodation by combining past knowledge with new information or situations. This argument is supported by the viewpoint of Güner and Erbay (2021) and Kilpatrick et al. (2001) who said it indicates that a person's MPSS will rise if he or she actively participates in solving mathematical issues alongside integrating acquired knowledge and experience. Therefore, past mathematical knowledge is believed to be relevant to MPSS.

In addition to the initial provision of mathematical knowledge, which may vary from person to person, each individual also possesses cognitive activity characteristics for solving mathematical issues. Cognitive style can characterize a person in the cognitive domain (Witkin, Moore, Goodenough, et al., 1977; Witkin, Moore, Oltman, et al., 1977). Since the 1950s, this cognitive style has been extensively researched by experts worldwide. This phenomenon happened because cognitive style is associated with how an individual chooses to process information or the numerous ways they choose to think and learn (Masalimova et al., 2019; Mefoh et al., 2017). Mefoh et al. (2017) demonstrate that cognitive psychology investigations reveal considerable disparities in the cognitive processing style a person employs when solving problems or making other decisions. Field-Dependent and -Independent are two types of cognitive styles (Witkin, Moore, Goodenough, et al., 1977; Witkin, Moore, Oltman, et al., 1977).

Mefoh et al. (2017) and Wapner (2009) describe the differences between Field-Dependent and -Independent cognitive types. A person with the Field-Dependent trait tends to think passively and globally and is easily distracted by their environment. A Field-Dependent has an advantage in social environment awareness. On the other hand, a Field-Independent cognitive style tends to comprehend and process information analytically and is not quickly impacted by its surrounding context. A Field-Independent is more interested in abstract and theoretical concepts. These distinctions necessitate an empirical investigation into whether the MPSS of individuals with the Field-Dependent and -Independent cognitive styles differ.

It is believed that disparities in prior mathematical knowledge and cognitive styles result in differences in information processing, which may have implications for differences in results. On the other hand, prior research on students' MPSS in terms of prior mathematics knowledge and cognitive style tended to be conducted separately and with qualitative analysis (Lee & Chen, 2009;

Mulbar et al., 2017; Nur & Palobo, 2018). Therefore, the results of the study did not provide significant evidence that there were differences in KPMM in terms of students' starting mathematical knowledge and cognitive styles.

The above-given context demonstrates the need to conduct an additional study to address this issue. Through this research, it is anticipated that the following objectives will be met:

O1) Analyzing and describing the level of prior mathematical knowledge, cognitive style, and students' MPSS.

O2) Analyzing the differences in MPSS based on prior knowledge of mathematics and students' cognitive style.

O3) Analyzing whether prior knowledge of mathematics and cognitive style have an interactive effect on students' MPSS.

2. Methods

2.1. Research Design

This survey-based study includes quantitative analysis. This survey-based study includes a quantitative analysis. The survey was conducted only on a portion (sample) of the population so that it is classified as a sample survey. In carrying out this survey, the researcher refers to the six steps given by Ary et al. (2014), which include planning, defining the population, sampling, constructing the instrument, conducting the survey, and processing the data.

2.2. Participants

This study used cluster sampling to select 182 kids from a junior high school in Bandung, Indonesia. There were 91 male and 91 female participants. Since 2017, Indonesia has established a zoning system for accepting new students at the elementary and secondary school levels, allowing for a more even distribution of student quality among schools (Bakar et al., 2019; Kemendikbud, 2018). Therefore, it is possible to generalize the findings in this study.

2.3. Data Collection

This study utilized the MPSS test, the prior mathematical knowledge test, and the Group Embedded Figures Test (GEFT) as its data mining instruments. The MPSS examination was created by modifying the MPSS indicators from the NCTM (2000) and Sumarmo (2012). The essential mathematical knowledge examination was created using the prerequisite material indicators of the MPSS examination. The validity and reliability of the MPSS test and first knowledge test have been established through testing. In the meantime, this study utilized the GEFT instrument to assess the cognitive styles of pupils. Mefoh et al. (2017) stated the GEFT is a standardized instrument frequently used to classify a person's cognitive styles as Field-Dependent or -Independent.

Students with a score of $0 \leq PAM \leq 55$ are classed as having little prior mathematical knowledge, $55 < PAM \leq 70$ are defined as having moderate prior mathematical knowledge, and $70 < PAM \leq 100$ are rated as having prior solid mathematical knowledge (Adaptation from Maya & Sumarmo, 2011)). Meanwhile, based on GEFT findings, students are classed as Field-Dependent if they can correctly answer no more than 11 questions and Field-Independent if they can correctly answer at least 12 of the 18 GEFT questions given.

2.4. Data Analysis

The descriptive quantitative approach and two-way analysis of variance (two-way ANOVA) with Jeffreys' Amazing Statistics Program (JASP) software were used to analyse the data in this study. The descriptive quantitative approach is used to describe the characteristics of the students, which include the students' prior knowledge of mathematics, cognitive style, and MPSS. Meanwhile, two-way ANOVA is an analytical tool to statistically study inferential variations in MPSS depending on prior mathematical knowledge and cognitive style.

3. Results

In this part, the research objectives-related findings are given. Following are student demographics and descriptive statistics on prior knowledge and cognitive style in relation to MPSS.

Table 1
Students' MPSS based on prior mathematical knowledge and cognitive style

PMK	*Cognitive Style*	*N*	*Mean*	*SD*	*SE*	*Coefficient of Variation*
High	FD	32	7.031	5.784	1.022	0.823
	FI	2	18.500	3.536	2.500	0.191
Low	FD	97	6.082	5.022	0.510	0.826
	FI	18	13.056	8.967	2.114	0.687
Mediate	FD	26	6.885	6.433	1.262	0.934
	FI	6	10.333	6.439	2.629	0.623

Note. MPSS ideal score = 40; PMK: Prior mathematical knowledge; FD: Field-depentent; FI: Field independent.

The descriptive data reveal that the most significant proportion of students based on their prior knowledge of mathematics is comprised of students with low prior knowledge of mathematics, which reaches 63.19%. In contrast, more than a third of the remaining was virtually similarly distributed between groups of students with intermediate and advanced prior mathematical knowledge. Based on cognitive style, more than four-fifths of the total sample of students belong to the Field-Dependent cognitive style. In contrast, less than 15% are Field-Independent cognitive style students. The research sample is dominated by Field-Dependent students with low initial mathematical knowledge, followed by Field-Dependent students with moderate and high initial mathematical knowledge, all of whom have a more significant proportion than Field-Independent students at any level of mathematical background.

According to Table 1, the group of students with the highest prior knowledge of mathematics and the best MPSS exam performance is the Field-Independent group, with a score of 46.25%. According to the classification, this performance is similar to a middling level Mogari and Lupahla (2013). According to the same classification, the achievement level of MPSS is poor for pupils with a Field-Independent cognitive style in both the mediate and low beginning mathematical knowledge groups. Students with the Field-Dependent cognitive style perform poorly in MPSS regardless of their amount of prior mathematics knowledge.

After testing the residual normality and data homogeneity assumptions, a two-way ANOVA was utilized to evaluate differences in students' MPSS based on their prior knowledge of mathematics and cognitive style. According to the residual normality test findings, the residual data are distributed near a straight line. Therefore, the residual normality assumption in this study has been satisfied. In the meantime, the variance similarity test (Levene's test) yielded a p-value of 0.065, which was inside the H_0 acceptability region. These results show that the data homogeneity assumption has also been met. Therefore, two-way ANOVA testing can be conducted. The findings of the two-way ANOVA test comparing students' MPSS depending on prior mathematical knowledge and cognitive style are shown in Table 2 below.

Table 2
Displays the results of the two-way ANOVA test of students' MPSS based on prior mathematical knowledge and cognitive style

Cases	*Sum of Squares*	*df*	*Mean Square*	*F*	*p*	η^2_p
PMK	94.585	2	47.292	1.361	.259	0.015
Cognitive Style	597.320	1	597.320	17.193	< .001	0.089
PMK ✻ Cognitive Style	95.133	2	47.566	1.369	.257	0.015
Residuals	6079.741	175	34.741			

Note. MPSS ideal score = 40; PMK: Prior mathematical knowledge.

According to the two-way ANOVA test findings, there was no difference in students' MPSS based on their prior understanding of Mathematics ($p > 0.05$). The cognitive style variable reveals the opposite finding. Table 2 indicates differences in the cognitive styles of the students' MPSS ($p < .05$) In addition, Table 1 reveals that the MPSS of students with a Field-Independent cognitive style is superior to that of students with a Field-Dependent cognitive style. Moderate cognitive style influences MPSS, as demonstrated by the partial eta value (Ary et al., 2014). Table 2 results further indicate no interaction between prior mathematics knowledge and cognitive style on students' MPSS ($p > 0.05$).

Figure 1
Descriptive plot of the interplay between prior mathematics knowledge and cognitive style on students' MPSS

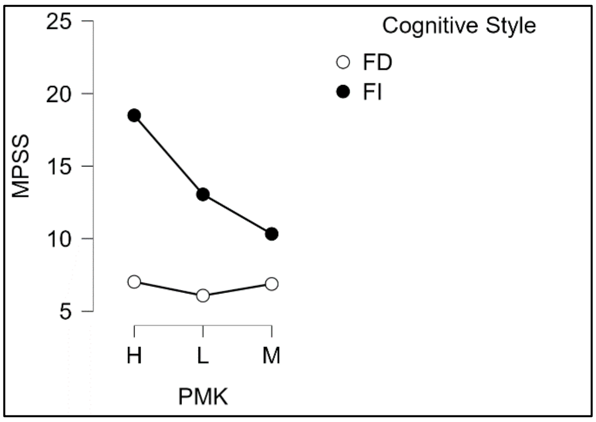

Figure 1 also supports the absence of this interaction effect, as the resulting curve exhibits no intersection. The MPSS of Field-Independent students is superior to Field-Dependent students at all levels of prior mathematical knowledge, as shown in Figure 1.

4. Discussions

This section offers a discussion of study results in relation to the established research objectives.

4.1. Prior Mathematical Knowledge, Cognitive Style, and the MPSS of Students

The comparatively low MPSS level of students is one of the most significant findings of this study. Few pupils with a Field-Independent cognitive style and strong beginning mathematical knowledge meet the intermediate-level MPSS benchmark. In contrast, the MPSS of pupils in other groups was categorized as low or extremely low. This fact supports the findings of prior studies indicating that pupils struggle to answer various queries using MPSS (OECD, 2019; Phonapichat et al., 2014; Sumirattana et al., 2017; Tambychik & Meerah, 2010). The implication of these findings is the need to facilitate the development of MPSS through the application of multiple effective learning models, media, and assessments, as well as the habituation of students to the orientation and process of solving mathematical problems in school mathematics education.

This study also revealed that the initial mathematical understanding of students needed to be improved. Almost two-thirds of the sampled pupils have low prior knowledge of mathematics, indicating the significance of this information. Supposedly, this is a result of the learning loss that occurred during the Covid-19 pandemic. Several studies have revealed that during the Covid-19 pandemic, there was a decline in students' mathematics skills compared to before the pandemic. Since 2021, however, there has been a small but insignificant increase (Kuhfeld et al., 2021, 2022; Kuhfeld & Tarasawa, 2020; Lewis et al., 2021; Patrinos et al., 2022). Consequently, when the spread of the Covid-19 virus is gradually contained, and face-to-face learning is reintroduced in schools, numerous efforts must be undertaken to enhance student competency, particularly in mathematics.

Another study finding revealed that only 14.19% of the students in the sample were identified as having Field-Independent cognitive styles. Meanwhile, more than four-fifths of students are Field-Dependent. According to Masalimova et al. (2019), distinct from Field-Independent students are relatively independent, disciplined, and critical, which enables them to focus and be persistent in problem-solving, analyse problems independently, produce new solutions, and develop problem-solving strategies. Field-Dependent students depend on others, such as teachers or friends, and rely on experience to help them develop problem-solving strategies. Therefore, Field-Dependent pupils must be exposed to a variety of scenarios and challenges in order to acquire problem-solving skills and the ability to adapt to new circumstances. This study's findings imply that the most students' MPSS development is significantly influenced by how teachers instruct, necessitating the adoption of a variety of strategies. This strategies, as described by Fraillig et al. (1999), Suryadi (2012), and Suryadi and Herman (2008) that we are beginning with discovering, encouraging, and developing students' mathematical thinking skills, particularly in solving mathematical problems.

4.2. Variations in MPSS Dependent on Prior Mathematical Knowledge and Cognitive Style

The second purpose of this study is to investigate the variances in MPSS based on prior mathematical knowledge and cognitive style. According to the findings presented in Table 2, there is no variation in students' MPSS based on their basic mathematical knowledge. This outcome contradicts the study's findings from Bahar and June Maker (2015) and Surya et al. (2017) which stated past mathematical knowledge influences student performance in solving mathematical issues.

Compared to prior mathematical knowledge, this study discovered that students' cognitive style influences MPSS. The finding is illustrated in Table 2. Tables 1 and 2 demonstrate that students with a Field-Independent cognitive style solve mathematical problems much better than students with a Field-Dependent cognitive style. In addition, the effect of cognitive style on students' MPSS was categorized as moderate in this study. Several prior research support this study's conclusions (Mulbar et al., 2017; Son et al., 2020; Ulya et al., 2014). This difference in MPSS occurs because of some reasons. Unlike Field-Dependent students, Field-Independent students are relatively independent, disciplined, and critical, allowing them to focus and persist in the problem-solving process and independently analyse problems, generate new solutions, and develop problem-solving strategies (Masalimova et al., 2019). In order to encourage the development of MPSS in pupils, students' cognitive styles must be taken into account when teaching.

4.3. The Interplay between Prior Mathematical Knowledge and Cognitive Style on Students' MPSS

Another finding in this research informs that there is no interaction effect between prior mathematics knowledge and cognitive style on students' MPSS. As illustrated in Figure 1, Field-Independent students fared better than Field-Dependent students at all levels of prior mathematical knowledge while solving mathematical problems. In the context of solving mathematical problems, Field-Dependent pupils' skills are highly influenced by their teachers' notions (Nur & Palobo, 2018). Although based on one of the provided criteria by Van de Walle et al. (2020), a problem is considered a mathematical problem if there is no anticipatory plan for its solution. This explanation emphasizes the causes of cognitive style-based disparities in students' MPSS.

5. Conclusion

There are some purposes of this study. First, to analyse and describe the level of students' prior mathematical knowledge, cognitive style, and MPSS. Second to analyse the differences in MPSS based on prior mathematical knowledge and cognitive style. Third, to analyse the interaction of the influence of prior mathematical knowledge and cognitive style on students' MPSS. This study provided several findings by referring to previous research and discussion results. Initially, the finding shows most pupils possess a Field-Dependent cognitive style and poor MPSS and early mathematical knowledge. Secondly, the MPSS of pupils is similarly based on their basic mathematical understanding. The moderate influence of cognitive style on MPSS variations between students is the last finding of this study. The outcome of this study is that there is no interaction between prior mathematics knowledge and cognitive style in students' MPSS. The implication implies that to improve students' MPSS, it is necessary to facilitate the development of MPSS by implementing various effective learning models, media, and assessments. Another implication is through the habituation of students in the orientation and process of solving mathematical problems during the learning and teaching of mathematics in schools while taking cognizance of students' cognitive styles. Consequently, future studies can examine adopting learning models that facilitate variances in cognitive styles to boost students' MPSS.

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