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Cognitive and socioeconomic factors that influence the mathematical problem-solving skills of students

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ABSTRACT

Mathematical problem-solving is necessary to encounter professional, 21st-century, and everyday challenges. The relevant context of mathematical problem-solving is related to science, which is presented using natural language. Mathematical problem-solving requires both mathematical skills and nonmathematical skills, e.g., science knowledge and text comprehension skills. Thus, several internal and external factors affect success in mathematical problem-solving. In this study, we investigated the cognitive (i.e., mathematics domain-specific prior knowledge (DSPK), science background knowledge, and text comprehension skills) and socioeconomic status (SES) (i.e., parents' educational level and family income) factors that affect students' mathematical problem-solving skills. The data considered in this study included tests, documents, and a questionnaire from grade seven to nine students ($n = 1067$). In addition, a theoretical model was constructed using structural equation modeling. We found that this model was close to satisfying the critical values of fit indices. The model was then modified by deleting the nonsignificant paths, and the modified model exhibited a better fit. We found that most of the exploratory variables directly affected mathematical problem-solving skills, with the exception of the parents' educational levels. The strongest factor was mathematics DSPK. Both the father's and mother's educational levels indirectly influenced mathematical problem-solving skills through family income. In addition, text comprehension skills indirectly impacted mathematical problem-solving skills with science background knowledge acting as a mediator.

1. Introduction

Education is the foundation of development and the essential tool for modern society [1,2]. Mathematics is a crucial skill that allows humans to understand the environment and obtain accurate accounts of physical phenomena [1,3]. Thus, mathematics education is critically important for lifespan [1,2].

The dynamic changing environment requires students to possess contemporary and transferable skills [4]. In addition, it is important to infuse mathematics into different subjects, such as science, because mathematics is a fundamental tool for understanding science, engineering, technology, and economics [1,4,5]. The science, technology, engineering, and mathematics (STEM) framework facilitates multidisciplinary education to solve a dynamic challenging environment [6]. Mathematics and science play a bidirectional and pivotal role; the former provides tools that can be used to represent, model, calculate, and predict quantitative relationships in

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science, while the latter provides a rich context in mathematics [5].

General reasoning ability, inductive and deductive reasoning, and divergent and convergent thinking are essential in mathematics that are assessed through mathematical problem-solving [7]. Problem-solving is a mandatory mathematics skill and the most suitable cognitive tool in mathematics education relevant to encounter professional, twenty-first-century, and everyday challenges [6,8,9]. Problem-solving is a cognitive or mental activity (including content and process) focused on transforming any situation into a goal situation when there are no direct ways to reach the goal [10,11]. Mathematical problem-solving is a thinking process wherein a solver tries to understand the problem situation using mathematical knowledge to obtain new information about the situation in order to reach the goal [11]. Hence, previous experience and prior mathematical knowledge are required to identify a problem [2]. Mathematical problem-solving has two main characteristics, namely, the task and process [11]. The task in mathematical problem-solving involves using realistic context that is presented through natural language in the form of a mathematics word problem [12]. The relevant realistic context of mathematical problem-solving is related to science [5]. In addition, there are overlapping frameworks among general problem-solving, science, and mathematics frameworks [6,9]. However, mathematical problem-solving in the science context has been identified by students as the most difficult to understand [13]. Thus, assessing students' mathematical problem-solving skills using a science context is applicable and necessary for contemporary education.

Students struggle with mathematical problem-solving even if they have mastered the mathematical computation skills required to solve the problem because they must identify both the relevant numerical information and the corresponding linguistic information in the text [12,14,15]. In other words, factors other than mathematical knowledge and skills influence mathematical problem-solving skills. Several researchers have discovered factors influencing mathematical problem-solving, namely, internal factors, such as resource, heuristic and method, control, and affect (belief, emotion, attitude, etc.), as well as external factors, such as demographic status, socioeconomic status (SES), and teachers' expectations [16–19]. Resource refers to formal and informal conceptual and procedural understanding and it is related to cognitive factors, including domain-specific prior knowledge (DSPK), text or reading comprehension, verbal ability, quantitative ability, etc. [16]. However, a study investigated the factors influencing mathematical problem-solving, including students' characteristics, family characteristics, parents' involvement, and school characteristics [20]. The most influential factors were family and students' characteristics, which accounted for 29.9% and 18% of variances, respectively. Family characteristics included family SES (parents' educational level, family income, etc.), and student characteristics included students' knowledge (cognitive). Hence, this study focuses on cognitive and SES factors influencing mathematical problem-solving skills.

The cognitive factors that influence mathematical problem-solving depend on the problem's structure and content [21]. Thus, students will succeed in mathematics problem-solving in the science context due to their prior knowledge and experience in mathematics and their nonmathematical knowledge, such as science knowledge [6,9] and text comprehension [7,12,14,22]. In addition to cognitive factors, external factors are also correlated with students' mathematical problem-solving skills, e.g., SES factors [2,23,24]. Parents' educational level, family income, and parents' occupations are indicators of SES [1,25–27].

Studies have proven that there is a strong correlation ($r \geq 0.4$) between mathematics knowledge and science knowledge in problem-solving because domain-specific knowledge is required in the problem-solving process [6,9,19]. In addition, several studies have demonstrated the importance of text comprehension in mathematical problem-solving [7,12,15] and science achievement [28–30]. However, these studies generally failed to consider all independent variables together using structural-equation modeling (SEM). In addition, many studies have confirmed the critical effect of the parents' educational level and family income as SES indicators on mathematical problem-solving [2,23,24]. However, they considered these variables as unconnected even though they are strongly related, e.g., the parents' educational level can affect family income [25,26].

Thus, this paper examines the cognitive and SES factors that influence science-related mathematical problem-solving skills. The cognitive factor focuses on mathematics DSPK, science background knowledge, and text comprehension skills. The SES factor emphasizes the parents' educational level and family income. The cognitive and SES variables will be directly and/or indirectly correlated based on previous studies, called a theoretical model. Hence, this study proposes the following research question. "To what extent do mathematics DSPK, science knowledge, text comprehension skills, parents' educational level, and family income variables interact in predicting students' mathematical problem-solving skills?"

The current study identifies these factors in a model analyzed by SEM, which can measure the simultaneous testing of relationships (both direct and indirect) rather than a single separate factor. The new model generated in this study is formulated based on previous studies. In addition, we compare the results from several developed models for more accurate and convincing results.

2. Theoretical background

A problem has been described as a gap between a current situation and a goal state [31]. Problem-solving is a cognitive process to understand, transform, and solve a problem when the solution is not immediately obvious [6,8]. Problem-solving is considered to be a process rather than the result itself [6].

Solving a problem represented using natural language by identifying important information in the text and applying mathematical knowledge is referred to as solving a mathematical word problem [14,32]. There are five foundational skills in mathematics education, that is, conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition [14]. When solving a mathematical word problem, most of these foundational skills are employed, such as, describing a real-world situation (productive disposition), applying concepts and procedures, using an appropriate strategy, and performing logical reasoning (strategic reasoning).

2.1. Mathematics DSPK and science background knowledge in mathematical problem-solving skills

Mathematics and science knowledge is highly related to reasoning and problem-solving [6], and the frameworks for general problem-solving, mathematical problem-solving, and science problem-solving overlap [6,9]. The overlapping of cognitive processes in mathematics and problem-solving involve structuring, mathematizing, processing, interpreting, and validating [5,9]. In addition, science is also related to problem-solving in terms of the application of knowledge, the performance of the inquiry process, and the relevant given context [9]. Thus, to realize successful mathematical problem-solving using the science context, students must master both mathematics knowledge and science knowledge.

The important role mathematics and science knowledge plays in problem-solving has been confirmed by several studies [6,9]. For example, a previous study demonstrated that mathematics and science are strongly correlated with complex problem-solving, exhibiting correlation coefficients of .492 and .401, respectively [6]. In addition, a study covering 41 countries investigated the contribution of mathematics and science competencies in analytical problem-solving and found that these competencies significantly contribute to problem-solving [9]. The authors also introduced the "math-science coherence" concept, which refers to the degree to which science and mathematics are harmonized as a feature of the educational environment.

Students' prior mathematics knowledge is significantly related to mathematical problem-solving [19,33]. Prior mathematical knowledge includes knowledge related to concepts, facts, definitions, relations, and operations (i.e., conceptual knowledge) and knowledge related to how and when to use the relevant procedures (i.e., procedural knowledge) [34,35].

Previous studies have revealed that conceptual and procedural knowledge influence mathematical problem-solving [35–38]. Mathematics DSPK accounted for 56% of the variance of problem-solving [37]. A study into algebraic problem-solving revealed that conceptual understanding in algebra explained 31% of the variance of problem-solving score [35]. A similar study concluded that conceptual knowledge about fractions was the most correlated factor ($r = 0.45$) influencing proportion problem-solving [36]. Moreover, another study reported that the ratio of students' mastery of prior algebra knowledge significantly predicted their achievement in solving algebra problem [19].

2.2. Text comprehension skills in mathematical problem-solving skills

Solving mathematical word problems requires the solver to identify the relevant linguistic and numerical information contained in the text [14,32]. Thus, it is necessary to possess both mathematical and linguistic skills (e.g., text comprehension skills) because students must comprehend the language of the text before applying an appropriate algorithm [14,22]. Students use their knowledge structures and networks by linking their prior knowledge to the information and concepts conveyed in a text [22].

Text comprehension is the construction of mental representation of the textual information to comprehend the text and merge it with prior knowledge [3,9,14]. Text comprehension skills include understanding the vocabulary of a context, identifying the main concept, noting detail, making inference, predicting outcomes, and forming conclusions [13]. Mathematics text differs from narrative or expository because mathematics employs a unique language, symbols, and vocabulary [3,22].

Studies have proven that text comprehension skills are strongly correlated to mathematical problem-solving [12,15,39]. For example, the correlation coefficients between mathematical word problem-solving skill and text comprehension skill were 0.45 and 0.38, respectively [15,39]. However, the model in a study involved a symmetric effect between mathematical problem-solving skills and text comprehension skills [39]. Mathematics problem-solving also affects mathematics achievement [7]. Text comprehension skills are correlated with mathematics achievement [3,14,40,41]. The text comprehension skills and mathematics achievement are demonstrating a correlation coefficient of 0.473 [3].

2.3. Text comprehension skills in science achievement

Text comprehension skills and science skills are interrelated, for example, identifying primary concepts and details, classification of concepts, constructing hypotheses, generalizing, and drawing conclusions [30]. Science text is more difficult than other types of text because it contains domain-specific vocabulary and employs both causal and sequential text schemas; thus, high text comprehension skills are crucial to realize high science achievement [30,42].

To the best of our knowledge, few studies have correlated text comprehension and science achievement, although they do form a symbiotic relationship [29]. Previous studies have demonstrated that text comprehension skills have a strong effect on science achievement [29,30,42]. Text comprehension accounted for 17% of the variance in science achievement [28], and the correlation coefficient between science achievement and text comprehension was greater than 0.24 [43]. A study compiled several factors influencing science achievement using SEM, and they concluded that, after prior knowledge, text comprehension was the second largest contributing factor [42]. However, in a different study, a weak correlation was found between science achievement and specific text comprehension indicators (i.e., understanding vocabulary, noting detail, predicting outcomes, and making inferences) [30].

2.4. SES in mathematical problem-solving skills

SES plays a crucial role in the health, well-being, socioemotional development, and academic success of children [26]. The impact of COVID-19 on teaching and learning resulted in widespread remote learning, which raised an issue regarding inequalities in academic achievement due to different SES [27,44]. SES factors include the parents' educational level, family income, parent involvement, and the parents' occupation [1,25,26]. Family income and occupation are related to the social and economic resources available to the student at a given time, and the parents' education level is a relatively stable aspect [26]. In this study, we focused on only the parents' educational level and family income because these are the first indicators of SES used in the psychology field [27].

It has been found that the parents' educational level influences both mathematics achievement and mathematical problem-solving skills [25,26,45,46]. The level of education of parents is related to the parents' beliefs and behaviors, for example, engaging in a good interactions, providing quality academic support, and communicating high expectations [25,27,47]. In addition, parents can transfer their intelligence and knowledge up to 10% through genetic, and up to 30% through environmental pathways [27].

Parents' educational level has an important role in predicting students' mathematical problem-solving [26]. However, the studies that investigated how parents' educational level affects mathematics achievement and mathematical problem-solving skills still have shown varied findings [1,20,26,46]. For example, one study showed that parents' educational level has an indirect association with mathematics achievement, with parental expectation and total achievement as mediators [25,26]. Several other studies have confirmed that parents' educational level are strongly correlated with mathematics achievement with a correlation coefficient greater than 0.40 [45,46]. In addition, another study concluded that parents' educational level is weakly correlated with mathematics achievement with a correlation coefficient of less than 0.20 [20]. However, different countries can show different results, for example, in America, the parents' educational level is associated with mathematics achievement; however, this is not observed in Hong Kong [48]. Different roles can also affect different results, and studies have revealed that the father's educational level has an impact on mathematics achievement but the mother's educational level does not [1,47]. Since parents' educational level in mathematical problem-solving has a crucial role but the former studies still have mixed results, including parents' educational level as one of the factors that influences mathematical problem-solving skills is necessary to demonstrate the relevance of this factor in the current study.

A study conducted for grades 5–11 revealed that the mother's educational level is associated with problem-solving skills across grades, and the father's level of education is only significant in grades 7 and 8 [8]. However, another result concluded that there is no association between the parents' educational level and mathematical problem-solving skills [2].

Several previous studies have reported the parents' educational level as a single variable rather than dividing it into two related variables, that is, the educational levels of both the mother and the father [25,46,48]. This means that there is a symmetric correlation between the education levels of the mother and father.

Typically, the parents' educational level drives their occupation and income [25,27]. A study constructed a model in which the parents' educational level influences the parents' occupation and family income, and they proved that parents' educational level influenced family income [26,27].

Family income is also associated with mathematics achievement [23,26,46]. It has been found that family income affects students achievement because it is related to the provision of material resources and is associated with family stress, which influences parenting [27]. Family income also has a positive effect on mathematics skills ($r = 0.268$) [46] that is greater than the parents' level of education [23]. An indirect relationship has also been found between family income and mathematics skills with parent expectation as a mediator [26]. However, another study stated that there is no relation between family income and mathematics skills [25].

2.5. Theoretical model of factors influencing mathematical problem-solving

Several factors affect mathematical problem-solving skills in the science context, including cognitive and SES factors. The cognitive factors include mathematics DSPK, science background knowledge, and text comprehension skills, and the SES factors cover the parents' educational levels and family income. These variables directly affect mathematical problem-solving skills. Text comprehension skills also influence science knowledge. Thus, science background knowledge can function as a mediator in the relationship between text comprehension skills and mathematical problem-solving skills. In addition, the parents' educational levels are correlated symmetrically, and they drive family income. As a result, family income can be a mediator for the association between the parents' educational level and mathematical problem-solving skills. Fig. 1 illustrates a theoretical model of the factors affecting mathematical problem-solving skills.

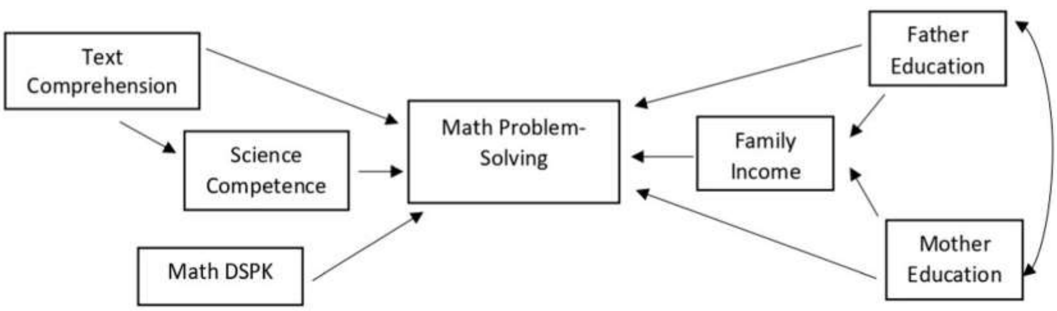

Fig. 1. Theoretical model of factors influencing mathematical problem-solving skills.

3. Method

3.1. Instrumentation

3.1.1. Science-related mathematical problem-solving test

The science-related mathematical problem-solving test is a scenario-based essay test with a mathematical scenario problem related to scientific phenomena. This test applies engineering based-design in the process of solving a problem using technology as a tool (e.g., calculator, grid paper, etc.). The test was developed under the integrated STEM-based mathematical problem-solving framework. It is a framework that applied the Program for International Student Assessment (PISA) creative problem-solving framework (exploring and understanding, representing and formulating, planning and executing, and monitoring and reflecting) as its core and combined other frameworks in every STEM discipline to construct indicators (i.e., scientific inquiry, engineering-based design, mathematics experimentation, and inquiry-based mathematics).

The test is targeted on grades seven to nine. In this test, there are three scenarios related to environmental management with one to two anchor scenarios for each grade. The total number of scenarios is six, i.e., “eco-friendly packaging” regarding designing an eco-friendly packaging and deciding the cheapest price (grade seven), “school park” regarding designing a planted school park with trees that can absorb the largest amount of CO_2 (grade seven), “calorie vs. greenhouse gas emission” regarding designing a 1-day-menu that fulfills the nutritional requirements and has the lowest CO_2 emission during their productions (grades seven to nine), “flood water reservoir” about designing a flood water reservoir and deciding the fastest time by pumps to absorb the average volume (grade eight), “city park” that has the similar idea with “school park” (grades eight and nine), and “infiltration well” regarding designing an infiltration well with complex constraints and determining the cost of its construction (grade nine). Each scenario involves a challenge pertaining to the topics of numbers and measurement, ratios and proportions, geometry, and statistics. Every scenario includes eight metacognitive prompt items to guide students to explore their problem-solving skills (e.g., the “Identifying the relevant and valuable given information” indicator includes the prompt “Mention the information that you need to answer the question!”).

The maximum score for each prompting item is five. A score of five indicates a complete and correct answer, four indicates a complete answer with a minor error, three indicates an incomplete but correct answer, two indicates an incomplete answer that contains an error, and one indicates a completely incorrect and irrelevant answer. The maximum score for each scenario is 40.

The psychometric evidence of the test was confirmed to be good and acceptable. The content validity index (CVI) value was greater than 0.67, the Cronbach Alpha was acceptable at .835, and the intraclass correlation coefficient (ICC) indicated moderate reliability ($r_{xx} = 0.628$). All scenarios and prompting items were fit ($0.77 \leq$ weighted mean-square ≤ 1.59). In addition, discrimination values ($0.48 \leq$ discrimination value ≤ 0.93), the behavior of rating score, and reliabilities (scenarios’ reliability = 0.860; prompting items’ reliability = 0.938) were acceptable.

3.1.2. Mathematics DSPK test

This test which was developed based on the Indonesian mathematics curriculum 2013, includes 30 multiple choice questions. The test is a single test for all grades. It measures students’ conceptual and procedural mathematical knowledge. The construct of conceptual knowledge is the knowledge of meaning which assesses students’ understanding about basic mathematical concepts (e.g., the meaning of the fraction concept). The construct of procedural knowledge includes the integration of knowledge and the application of knowledge. Integration of knowledge targets interrelation among concepts in the understanding, planning, and evaluating phases (e.g., finding the correct statement regarding the problem-solving process). Application of knowledge focuses on applying knowledge in the application phase (e.g., calculating the reduction of CO_2 emission).

The topics used are applied in the science-related mathematical problem-solving test and intersection topics in all graders based on the Indonesian curriculum 2013. The topics covered in this test include numbers (integers and fractions; nine questions) and measurement (four questions), ratios and proportions (eight questions), geometry (four questions), and statistics (five questions). Each topic involves four phases: understanding a basic concept (conceptual knowledge), interrelation among concepts in planning, executing, and evaluating (procedural knowledge). The test uses a science or social context. The test was designed as a set of interdependent multiple-choice items that represent a process, making it flexible to assess concepts and procedures (DSPK).

There are four options in every item with distractions. These distractions are designed based on the consequences of choosing the wrong answer in the previous item, as well as some common misconceptions, errors, and difficulties that students often encounter.

The test has a total score of 30, with 1 point awarded for the correct answer and 0 point for an incorrect answer. The psychometric evidence was confirmed to be good. The CVI values were greater than 0.83, and the ICC was acceptable (r_{xx} = . 513). The construct of all items indicated fit ($0.90 \leq$ weighted mean-square ≤ 1.16) and were reliable ($\alpha = 0.74$) with various difficulty levels.

9. Text comprehension and science grades

The text comprehension grade was obtained from the diagnostic test scores for an Indonesian language literacy test. This language literacy test was a sample-based test for Indonesian students. At the beginning of an academic year, schools typically perform diagnostic assessments of students using a single test provided by Ministry of Education. The constructs of all the items indicated fit ($0.79 \leq$ weighted mean-square ≤ 1.43) and were reliable (EAP/PV reliability = .94). This test involves 21 items in finding information (7 items), interpreting and integrating the information (8 items), and evaluating and reflecting (6 items). There are three texts, namely narrative scientific text, scientific news text, and poetry text. In addition, this test involves simple and complex multiple-choice questions, short-answer questions, an essay, and matching type questions. The scores for this 60-min test are presented as percentages. Since the test is valid; hence students' grades from the test were used in the current study to assess the text comprehension skills.

The science grade was received from the mean score of the diagnostic tests scores relative to the environmental science topic provided by the books from the Indonesia's Ministry of Education. The tests are multiple-choice tests. Every school has to use the same tests within grade before learning every chapter. However, the tests are not the same test across grades, only have the similar competency indicators (e.g., the same test is used for grade 9 in all schools; however, the test for grade 9 is different from grade 7 despite similar indicators). The indicators are related to energy and photosynthesis (the plant organs involved in photosynthesis, the products of photosynthesis, factors affecting photosynthesis, experiments related to photosynthesis, the materials used in photosynthesis, and technologies inspired by the photosynthesis process), cause and effect of environmental issues and climate change (the greenhouse effect, methods to reduce greenhouse gas emissions, preventive actions against global warming, and the ozone layer), eco-friendly products (examples of eco-friendly products and their advantages), health and nutrition (nutrients, experiments related to nutrients, examples of foods containing vitamins and nutrients, and the functions of vitamins and nutrients in the body), biotechnology (examples of biotechnology products, the differences between conventional and modern biotechnology, and the effects of biotechnology) and scientific procedure (concepts of data, variables, and scientific procedures). There are 9 items in every test with four options. The mean score was converted into a percentage to facilitate uniformity.

The contents of the tests were confirmed valid and reliable with the CVI between 0.67 and 1. The results of the reliability of the tests for grades 7 to 9 were 0.98, 0.96, and 0.92, respectively.

3.1.3. SES questionnaire and document

The SES questionnaire covers the questions regarding parents' educational level both the father and mother (from elementary school to doctoral), family income (four categories based on the average level of the income in the province), and the number of siblings. The SES questionnaire was validated by teachers before administration. The information given is confirmed using the students' SES data from schools. The SES data from the schools are the official school data received from parents. Here, family income was grouped based on the total amount of the parents' incomes relative to the number of dependent children.

3.2. Participants

The population of the study included middle-school students (grades 7 to 9) from A-accreditation schools in both rural and urban areas in East Java, Indonesia. The Indonesia's Ministry of Education assesses the accreditation based on environment, human resources, and teaching and learning process. The highest accreditation is A-accreditation. There are 1886 A-accreditation schools in East Java, Indonesia, with a total of approximately 2 million students (npd.kemendikbud.go.id). Given the population, this study needs 1067 samples by applying a confidence level of 95% and a confidence interval of 3. Hence, we recruited 1067 participants and applied a stratified random sampling method. We chose schools in urban and rural areas and random classes in each grade. Table 1 describes the characteristics of the participants.

3.3. Data analysis

In this study, we investigated the effect of independent variables (i.e., mathematics DSPK, science background knowledge, text comprehension skills, parents' educational levels, and family income) on students' mathematical problem-solving skills. Here, we employed SEM with a maximum likelihood (ML) estimator, and the type of data was correlations and standard deviations. The SEM analysis was performed using the Mplus version 8.0 application.

To ensure the model fit, we investigated the Chi-squared test values, the comparative fit index (CFI), the root mean squared error of approximation (RMSEA), the Tucker–Lewis index (TLI), and the standardized root mean square residual (SRMR). The CFI and TLI

Table 1
Characteristics of participants.

Demographic characteristics		N	%
Gender	Boys	452	42.4
	Girls	615	57.6
Grade	7 (M age = 12.59, SD = 0.61)	380	35.61
	8 (M age = 13.42, SD = 0.59)	331	31.02
	9 (M age = 14.50, SD = 0.59)	356	33.36
School location	Rural	427	40.02
	Urban	640	59.98
Ethnic	Javanese	1015	95.01
	Madurese	35	3.3
	Batak	2	0.20
	Java-Madurese	3	0.29
	Sundanese	5	0.50
	Betawi	2	0.20
	Others	5	0.50

values were categorized as good if they were greater than or equal to 0.95; however, they are still acceptable with a value of approximately .90 [49]. In addition, a good SRMR value is less than 0.08 [49], and the RMSEA value was considered acceptable if it was less than 0.08 and marginal if it was in the range [0.08, 0.10] [50]. The model fit will be improved by creating a modified model. After we obtained a fit model, we examined the independent variables that influence mathematical problem-solving skills according to the significance values and correlation coefficients. In addition, we identified the standardized estimates in terms of their direct effect, indirect effect, and total effect for all independent variables.

3.4. Procedure

The data collection process was performed from July to September 2022. Note that the researchers applied for ethical approval from the institutional review board (IRB) of the university and were granted with the ethical approval number of 7/2022 prior to collecting the data. The ethical approval letter was given to several schools and they asked to response their participation. After confirming participation, the researchers discussed the data collection procedure with mathematics teachers.

On the first day, the students were asked to take the science-related mathematical problem-solving test for 3 h (with a break in every hour) using a paper-based technique. Then, on another day, the students used an online platform to take the mathematics DSPK test (90 min) and SES questionnaire (15 min). In addition, the students' grades for science and text comprehension were requested from the schools. These students' grades documents will be employed to assess students' science knowledge and text comprehension skills.

The students' answers for the science-related mathematical problem-solving test were scored by two raters, an author and a teacher who graduated with master's degrees in mathematics education, to ensure the consistency of the implementation of the rating scale. The obtained ICC value was 0.992, which indicates good and consistent ($\alpha = 0.996$). The data from tests, documents, and the questionnaire were used to calculate the correlations and standard deviations. The correlations and standard deviations data were then used to analyze the theoretical model of factors influencing mathematical problem-solving skills using SEM.

4. Results

4.1. Descriptive statistics

Before reporting the results of the descriptive statistics, we first describe the students' performance in the mathematical problem-solving task to demonstrate the variation in their performance levels. Students' performance in science-related mathematical problem-solving is categorized as average (M = 60.49, SD = 19.266). Overall, 52.1% of students scored below average. The students' performance based on the grade showed that grade 8 students achieved the highest mean score (M = 61.98, SD = 20.35), followed by students in grade 9 (M = 60.81, SD = 13.82) and grade 7 (M = 58.89, SD = 22.36). According to the level of the mothers' education, students with mothers holding a master's degree exhibited the highest performance in science-related mathematical problem-solving (M = 67.82, SD = 20.53), followed by students with mothers holding a doctoral degree (M = 63.28, SD = 11.84), bachelor's degree (M = 61.17, SD = 19.30), high-school degree (M = 61.10, SD = 19.09), middle-school degree (M = 58.84, SD = 20.06), and elementary school degree (M = 55.37, SD = 18.62). However, the pattern differed based on the fathers' educational level. Students with fathers holding a bachelor's degree performed better (M = 63.92, SD = 19.41) compared to those with fathers holding a master's degree (M = 62.79, SD = 19.55), doctoral degree (M = 61.46, SD = 22.52), high-school degree (M = 60.55, SD = 18.79), elementary school degree (M = 59.97, SD = 20.58), and middle school degree (M = 54.78, SD = 19.40). In addition, students from low family income demonstrated the lowest performance in science-related mathematical problem-solving (M = 59.36, SD = 19.00) compared with students from middle family income (M = 63.59, SD = 19.82) and high family income (M = 68.22, SD = 18.65).

In the following, we report the variation and association of the observed variables obtained from the given data through standard deviations and correlation coefficients to infer causality. Table 2 shows the correlation coefficients and standard deviations for each variable.

The standard deviations of the variables are large indicating that the data is quite spread out or there might be outliers. However, it is not necessary to remove the outlier data since it is not noise data. In addition, deleting the outlier does not influence the model due to the large sample size. All variables were correlated significantly, except the association between the father's educational level, the

Table 2
Correlation coefficients and standard deviations of variables.

Variables	1	2	3	4	5	6	7
1. Mathematical problem-solving skill	1						
2. Math DSPK	.668**	1					
3. Science knowledge	.590**	.362**	1				
4. Text comprehension skill	.498**	.376**	.294**	1			
5. Mother's education	.095**	.032	.108**	.056	1		
6. Father's education	.090**	.034	.092**	.033	.563**	1	
7. Family income	.113**	.017	.081**	.078*	.381**	.364**	1
SD	19.266	4.025	29.819	16.727	.944	.887	.505

**p < .01; *p < .05.

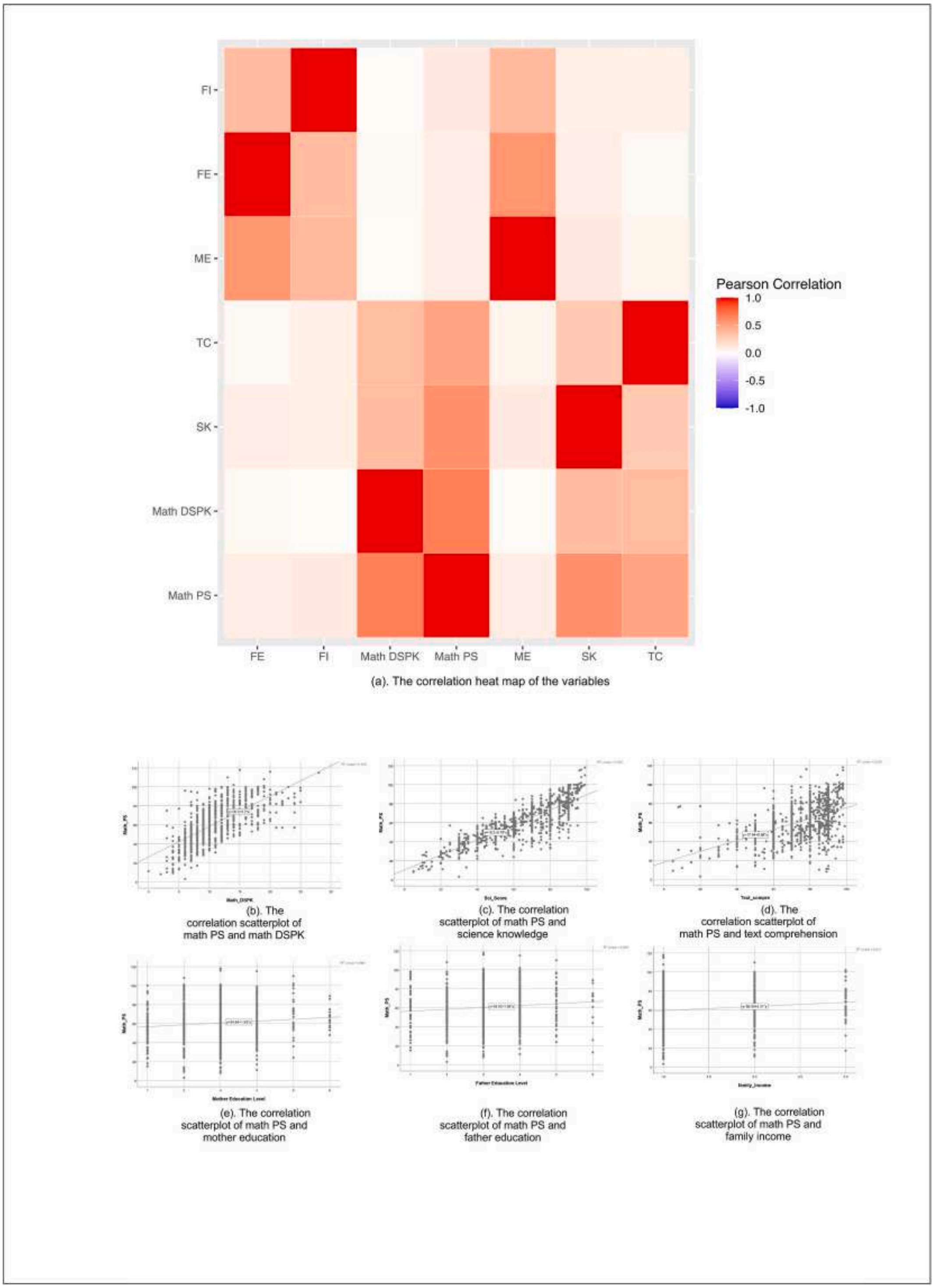

Fig. 2. (a) The correlation heat map of the variables; (b) The correlation scatterplot of mathematical problem-solving and mathematics DSPK; (c) The correlation scatterplot of mathematical problem-solving and science knowledge; (d) The correlation scatterplot of mathematical problem-solving and text comprehension; (e) The correlation scatterplot of mathematical problem-solving and mother education; (f) The correlation scatterplot of mathematical problem-solving and father education; (g) The correlation scatterplot of mathematical problem-solving and family income.

mother's educational level, and family income and mathematics DSPK. In addition, no significant correlation was observed between the father or mother's educational level and text comprehension skills. The strongest correlation was found between mathematical problem-solving skills and mathematics DSPK. We also found weak correlation coefficients or correlation coefficient less than 0.4, which may cause a problem of insignificant association in the loading of the measurement model. For example, the correlation coefficient between father's educational level and mathematical problem-solving skills was 0.090. Fig. 2 represents a correlation heat map and correlation scatterplots of the variables.

4.2. Goodness of fit indices

In the following, we discuss five goodness of fit indices, i.e., χ^2, CFI, TLI, RMSEA, and SRMR. We found that the CFI, TLI, and SRMR results are acceptable. Although the TLI is less than 0.90, but it is relatively close to 0.90. The TLI value close to 0.90 indicated that the model is fit, but needed improvement since it was less than 0.90. The RMSEA result is considered marginal. According to the results for several of the goodness of fit indices, the model was categorized as a fit model; however, it was close to the minimum criteria of TLI, CFI, RMSEA, and SRMR.

Thus, we attempted to improve the results in terms of the goodness of fit indices by producing Model 2, which does not include a direct path from the parents' education level to mathematical problem-solving. In the first model, we obtained a nonsignificant p value in the direct path of the parents' education level to mathematical problem-solving. Here, the CFI, TLI, RMSEA, and SRMR results are acceptable. Even though the RMSEA value for Model 2 was close to 0.08, we found that Model 2 obtained better goodness of fit results. Table 3 represents the results of the goodness of fit indices of Model 1 and Model 2.

4.3. Estimates of structural model

Theoretical Model 1 was analyzed, and we found that two independent variables were not significantly associated with mathematical problem-solving skills, i.e., the father's and mother's educational levels. This means that the parents' educational levels do not directly influence mathematical problem-solving skills. The most influential variable was mathematics DSPK ($r = 0.478$). We also found that all cognitive factors strongly influenced mathematical problem-solving skills rather than the SES factors. With Model 2, we found that all independent variables significantly affected mathematical problem-solving skills, where mathematics DSPK ($r = 0.478$) remained the most influential variable. Table 4 shows the standardized estimates of the structural model of Models 1 and 2.

4.4. Mediating effect of structural model

The results for both Models 1 and 2 indicated that mathematics DSPK had the largest total effect, followed by science background knowledge and text comprehension skills. According to theoretical Models 1 and 2, text comprehension skills influence mathematical problem-solving mediated by science knowledge. This means that text comprehension skills can indirectly influence mathematical problem-solving through science knowledge. The results for Model 1 demonstrated that text comprehension skills affected mathematical problem-solving skills both directly ($r = 0.228$) and indirectly ($r = 0.109$). However, the direct effect was greater than the indirect effect. A similar result was obtained with Model 2, where the direct effect of text comprehension skills was stronger than the indirect effect. Although the total effect of text comprehension skills on mathematical problem-solving skills in Models 1 and 2 was the same, in Model 1, the direct effect was greater, and the indirect effect was less than that of Model 2.

The results obtained for Model 1 indicated that the parents' educational levels do not significantly or directly affect mathematical problem-solving skills. However, both of these variables influenced mathematical problem-solving skills indirectly through family income, but the effects were weak ($r_{motheredu} = 0.014$ and $r_{fatheredu} = 0.012$). For Model 2, when the direct association between mathematical problem-solving skills and the parents' educational levels were removed, the indirect effects of both variables on mathematical problem-solving skills were stronger. The effect of family income was also stronger in Model 2. Table 5 shows the mediating effect of the structural Models 1 and 2 (Figs. 3 and 4 show the standardized coefficients of Models 1 and 2).

5. Discussion

Mathematical problem-solving in the science context has been identified as the most difficult skill for school age students because such problems are typically presented using natural language; thus, students must be able to understand the meaning of the problem's text prior to applying mathematical concepts [12–15]. In addition, science is integrated as a context of the mathematical problem;

Table 3
The results of the goodness of fit indices of model 1 and model 2.

	Model 1	Model 2
χ^2	$\chi^2(10) = 110.435$, $p < .001$	$\chi^2(12) = 110.994$, $p < .001$
CFI	.931	.932
TLI	.897	.915
RMSEA	.097	.088
SRMR	.076	.076

Table 4
Standardized estimate of structural model of Models 1 and 2.

Endogenous variable	Exploratory variable	Model 1			Model 2		
		Standardized estimate	S.E.	*P*	Standardized estimate	S.E.	*p*
Mathematical problem-solving skill	Mathematics DSPK	.478	.020	<.001	.478	.020	<.001
	Science knowledge	.372	.020	<.001	.373	.020	<.001
	Text comprehension	.228	.022	<.001	.227	.022	<.001
	Mother's education	.001	.024	.955	–	–	–
	Father's education	.015	.024	.533	–	–	–
	Family income	.056	.022	.009	.062	.020	.001

Note: "-" indicates that there is no path between these variables.

Table 5
Mediating effect of structural models 1 and 2.

Endogenous variable	Exploratory variable	Model 1			Model 2		
		Direct effect	Indirect effect	Total effect	Direct effect	Indirect effect	Total effect
Mathematical problem-solving skill	Mathematics DSPK	.478*	–	.478*	.478*	–	.478*
	Science competencies	.372*	–	.372*	.373*	–	.373*
	Text comprehension	.228*	.109*	.337*	.227*	.110*	.337*
	Mother's education	.001	.014*	.015*	–	.016*	.014*
	Father's education	.015	.012*	.027*	–	.014*	.016*
	Family income	.056*	–	.056*	.062*	–	.062*

Note: "-" indicates that there is no path between these variables.
*p < .01.

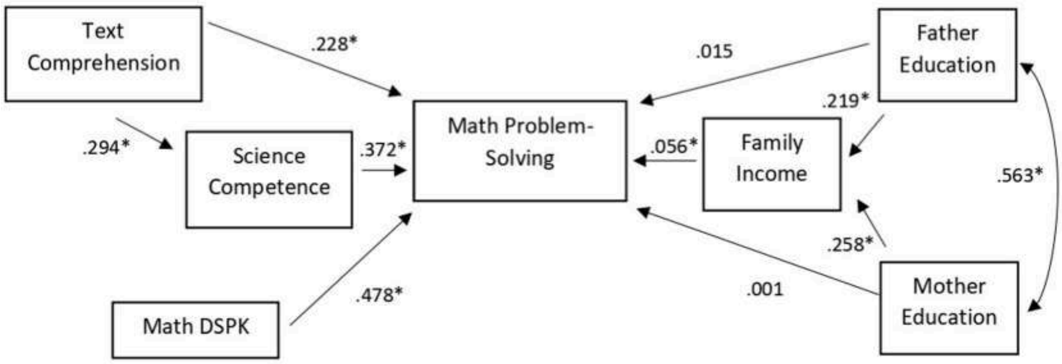

Fig. 3. Standardized coefficients of Model 1.

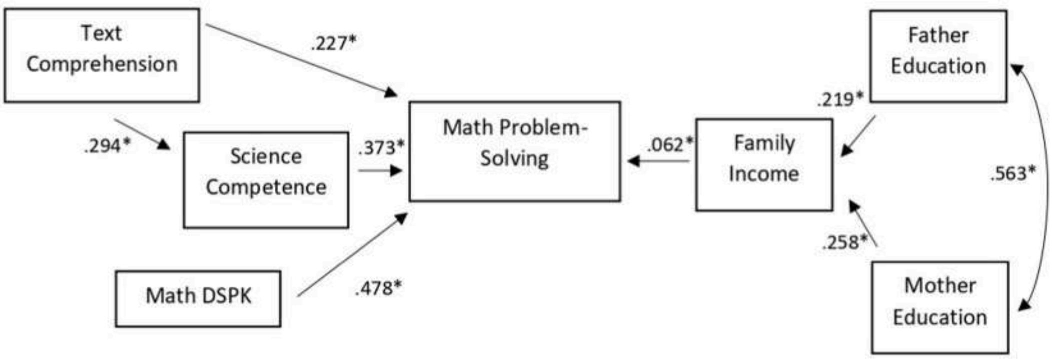

Fig. 4. Standardized coefficients of Model 2.

thus, students should have sufficient science knowledge to be successful in solving it [6,9]. Therefore, success in mathematical problem-solving is obtained through a strong mathematics DSPK and knowledge in both science and text comprehension skills [6,9,12,14].

In addition to cognitive factors, the SES factor also contributes to success in mathematical problem-solving [25–27]. The first indicators of SES in psychology research were the parents' educational level and family income [27]. These factors have been shown to contribute to success in mathematical problem-solving [23,26,46,47]. The parents' educational level leads to positive behaviors and beliefs [25,27,47], and family income affects mathematical problem-solving skill through the provision of material resources [25,27].

In this study, we constructed a theoretical model of factors that affect mathematical problem-solving skills, called Model 1. In this model, the exploratory variables included mathematics DSPK, science background knowledge, text comprehension skills, the mother's educational level, the father's educational level, and family income. In this theoretical model, these variables had a direct association. However, we also found that text comprehension also had an indirect effect through science knowledge. Understanding a science problem requires text comprehension skills because science problems contain words and involve unique vocabulary [28–30,43]. We also found that the parents' educational levels have an indirect effect through family income in the theoretical model because higher educational levels tend to lead to higher incomes [25,27].

The goodness fit results for Model 1 were acceptable; however, the RMSEA value was marginal, and the TLI value was close to the cut-off point which is 0.90 [49,50]. Overall, Model 1 was acceptable; however, improvements were required. A model can be modified by adding parameters and paths to increase model complexity or remove unnecessary parameters and paths to create a simpler model [51]. In this study, we decided to remove the direct association between the father and mother's educational levels and mathematical problem-solving skills because there were no significant effects in the model. The modified model, i.e., Model 2, obtained better CFI, TLI, RMSEA, and SRMR results, which indicated that Model 2 exhibited acceptable goodness of fit [49,50].

The largest correlation coefficient was between mathematical problem-solving skills and mathematics DSPK ($r = 0.684$). It means that mathematics DSPK is the strongest factor influencing mathematical problem-solving skills ($r = 0.478$). This result was similar to results reported by previous studies, i.e., mathematics knowledge is strongly correlated to problem-solving, and the correlation coefficient was greater than 0.40 [6,35,36,38]. In mathematical problem-solving, students must utilize mathematics knowledge in the knowledge application phase; thus, prior mathematics knowledge is a crucial factor to realize successful mathematical problem-solving skills [8,19].

Science background knowledge was the second strongest factor affecting problem-solving skills. ($r = 0.373$), and this result is in agreement with a study's findings [6]. In addition, in mathematical problem-solving in the science context, science knowledge contributes in the application of knowledge and the performance of the inquiry process [9]. Thus, the notion that science competencies influence mathematical problem-solving in the science context was predicted effectively. However, the correlation coefficient of science knowledge and mathematical problem-solving in the current study is weaker than that observed in previous studies, although the correlation is still relatively high [6,9].

We found that text comprehension skills have both direct and indirect effects on mathematical problem-solving skills, and these results confirmed the finding of previous studies [3,14,40,41]. Mathematical problem-solving is typically presented using natural language, and to solve problems, students must understand the information and build mental representations using text comprehension skills [14,32]. However, the correlation coefficient of the text comprehension skills and mathematical problem-solving skills in the present study is weaker than that reported in previous relevant studies. According to the results, text comprehension also affected science competencies, which is also in line with the results of previous studies because a science problem presented in linguistic form requires students to comprehend the text to solve it [29,30,42,43]. An indirect effect of text comprehension skills on mathematical problem-solving skills was identified with science competencies functioning as a mediator ($r = 0.110$). This indirect effect has not been considered in previous studies.

The results revealed that the correlation coefficients of the parents' educational levels on mathematical problem-solving were not significant. In Model 1, the parents' educational levels did not significantly or directly affect mathematical problem-solving skills. It is in accordance with the results of previous studies [2,48] and contradicts with the majority results [25,26,45,46]. The culture and social interaction of different countries affect the results of the relationship between parents' educational level and mathematical problem-solving skills [48]. We hypothesize that the nonsignificant correlation of parents' educational level and mathematical problem-solving is due to (1) the trend of full working time for parents in Indonesia; and (2) well-educated parents are not always having economically well-being. Parents, both the mother and father, with high levels of educational tend to work from 9 a.m. to 5 p.m. (or more); thus, they have less time to focus on their children. The second hypothesis is related to the change in work skills to contemporary skills. Thus, a high level of educational will not guarantee a better job. However, we must confirm these hypotheses. In Model 1, there is no direct effect from the parents' educational level; thus, we constructed Model 2, which did not include a direct relationship between the parents' educational levels and mathematical problem-solving skills.

This phenomenon contributed to the results reported in previous studies, i.e., there is another factor that mediates the association between the parents' educational levels and mathematical problem-solving skills [2,25,26]. According to the empirical results of Models 1 and 2, the results agreed with the previous studies that found the mother and father's educational levels influenced mathematical problem-solving skills indirectly [25,26]. Here, the mediating variable was family income, which is different from previous studies. We found that family income directly affects mathematical problem-solving skill, which is in agreement with the results of several studies [23,46], but contradicts one [25]. However, the effect was weak compared to the former studies. In Model 1, the direct effect of family income was less than that in Model 2 because in Model 2 we removed the paths of nonsignificant variables.

6. Conclusion

Mathematical problem-solving in the science context involves complex skills, both mathematical and nonmathematical skills. In this study, we constructed two theoretical models, i.e., the original model and a modified model (Models 1 and 2, respectively), to analyze the factors that influence mathematical problem-solving skills. We found that both models obtained acceptable results; however, according to the results, the modified Model 2 exhibited better goodness of fit indices.

This study confirmed several cognitive and SES factors that influence mathematical problem-solving skills, and we identified both direct and indirect effects. We found cognitive factors have a greater effect than SES factors. The cognitive factors that directly influence mathematical problem-solving were mathematics DSPK, science background knowledge, and text comprehension skills, with mathematical DSPK being the factor with the greatest influence. Text comprehension skills were also found to indirectly affect mathematical problem-solving skills through science knowledge.

Family income was only the SES factor that directly affected mathematical problem-solving skills. The parents' educational levels were found to have an indirect effect on mathematical problem-solving skills through family income. The reasons regarding less time spending with children and economic well-being were still needed to be confirmed.

This study has limitations relative to the limited number of variables in the SES factors, the data source or instruments, and the large standard deviation. In this study, we only covered two SES indicators; however, there are several other SES indicators are known to affect mathematical problem-solving skills (e.g., parents' occupation and family structure). These potential unmeasured variables are predicted to have impact on students' mathematical problem-solving skills. The second limitation was that the score of science knowledge was from the score of diagnostic tests that were conducted not using a single test, but only using the tests that have the same constructs, contents, and indicators of competencies. In addition, the categories of parents' educational levels are relatively general, and they may not adequately reflect the complex facets of parents' educational experiences, such as the disciplines they studied or the depth of their mathematical knowledge. These aspects may influence parental support and students' exposure to mathematical concepts at home. Hence, it is considered using more precise instrument for assessing parents' education. The third limitation was that the variables have large standard deviations, which require further investigation.

Despite these limitations, the results of this study can be used by teachers to consider the factors that strongly affect mathematical problem-solving. Thus, teachers can better prepare appropriate teaching and learning strategies that consider and include these factors. Teachers should consider mathematical DSPK and science knowledge before introducing complex subject matter, e.g., mathematics problem-solving in the science context. Since mathematics DSPK is the strongest factor influencing mathematical problem-solving, it is suggested to (1) recall students' mathematics prior knowledge before mathematical problem-solving activity; (2) enhance students' mathematics prior knowledge in the most difficult knowledge and mathematics topics; and (3) design a comprehensive teaching and learning approach to improve students' prior knowledge when such knowledge is needed but appears to be poor. In addition, to consider science knowledge and text comprehension skills factors, it is necessary to familiarize students with nonroutine word problems in the science context using a constructivist teaching method (e.g., mathematics inquiry-based learning).

Future study is wide open for researchers in relevant fields. For example, the present study was conducted in a large sample size; hence the results can serve as a basis for relevant studies aimed at determining factors that influence mathematical problem-solving skills. However, the generalization of the results of this study is limited to the Indonesian context. The theoretical model examined in this study can be adapted or replicated for relevant studies to be conducted in different demographic backgrounds (e.g., different countries). This adaptability is possible because the theoretical model is formulated based on previous studies from several different contexts. The analysis of the adapted model in the sample from different countries will create a strong basis for generalization regarding the factors impacting mathematical problem-solving skills. In addition, it is possible to consider additional variables in terms of the SES factors.

Author contribution statement

Ijtihadi Kamilia Amalina: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Tibor Vidákovich: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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