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How Does Working Memory Capacity Affect Students' Mathematical Problem Solving?

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Abstract: Problem-solving process requires information processing, and the information processing is related to working memory capacity (WMC). This study aims to determine the effect of WMC on students' mathematical abilities and to describe the ability of the students with high and low WMC in solving mathematical problems. This research used mixed method with Sequential Explanatory Design. The quantitative data were collected through the provision of OSPAN tasks and math tests to 58 students aged 15-17 years, while the qualitative data were collected through interviews based on mathematical problem-solving tasks. The results showed that WMC had a significant effect on students' mathematical abilities (R=0.536; p=0.000). Researchers found differences in students' mathematical problem-solving abilities with high and low WMC. Students with high WMC can remember and manage information well which supports the determination of more advanced problem-solving strategies and have better attention control so that they find varied appropriate solutions. Students with low WMC experienced decreased attention control as the complexity of the tasks increased, missed important information in problem solving strategies, and did not recheck their work, leading to wrong solution/answer. The mathematical performance of students with high WMC outperformed the mathematical performance of students with low WMC.

Keywords: *Mathematical ability, problem solving, working memory capacity.*

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Introduction

Mathematics is essential in technological development and needs to be given to students to face new situations, one of which being the digitization of the 21st-century society (Gravemeijer et al., 2017; Ünal, 2017). From a theoretical perspective, Krutetskii (1976, as cited in Karsenty, 2014) defines mathematical ability as acquiring, processing, and storing mathematical information, or as the capacity to learn and master new mathematical ideas and skills. Meanwhile, from evaluation perspective, *mathematical ability* is defined as the ability to perform mathematical tasks and solve given mathematical problems (Karsenty, 2014).

Problem-solving is one of the mathematical abilities that students need to master. As mentioned by National Council of Teachers of Mathematics (NCTM, 2000), mathematical ability consists of five components, namely: (1) mathematical communication, (2) mathematical reasoning, (3) mathematical problem solving, (4) mathematical connections, and (5) representations. Problem-solving is elucidated by Hesse et al. (2015) as an individual activity to respond to or to overcome obstacles when a solution or the method of finding a given solution is not yet clear. Obstacles occur when the individual feels a discrepancy between the current state and the desired goal state.

Supporting students to become problem solvers can be helpful in their daily lives. Thus, they gain experience in thinking to develop their abilities. To connect students with real situations and explore new ideas, problem-solving skills need to be trained in the learning process (Anjariyah et al., 2018; Arum et al., 2018; Firdaus et al., 2021). Mathematics can be applied in real life through problem-solving. In previous researches that have been conducted (Căprioară, 2015; DeCaro, 2018; Mayfield & Chase, 2002; Tohir et al., 2020), problem-solving activities positively impacted the thinking process. Students got the opportunity to face difficulties by utilizing the combination of knowledge they had about concepts, procedures, and calculations efficiently in a well-defined context.

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The process of solving mathematical problems in this study used Polya's (1973) steps, namely understanding the problem, devising a plan to solve the problem, carrying out the plan, and looking back. When students are involved in problem-solving, they use thinking process to understand the problem and identify the facts or information provided. According to Wang and Chiew (2010), problem-solving is the brain's cognitive process to find solutions to a given problem or to find a way to achieve specific goals. This cognitive process is related to working memory.

Baddeley et al. (1975) and Bayliss et al. (2005, as cited in Juniati & Budayasa, 2020) define *working memory* as a term that refers to a person's cognitive system that maintains and processes information to complete the task being performed. Stillman (1996) explains that working memory is related to cognitive resources which are used to carry out mental operations and remember the results of these operations for a short time. Working memory that plays a role in this cognitive task has a limited capacity (G. A. Miller, 1956; Unsworth et al., 2009).

Several experts have studied working memory capacity (WMC) and problem-solving. In science, Solaz-Portolés and Sanjosé-López (2009) showed a positive correlation between working memory and science problem-solving. The research conducted by Wiley and Jarosz (2012b) revealed that WMC affects problem-solving, but not always positively, depending on the problem-solving (analytic or creative problem solving). In line with Wiley and Jarosz's research, DeCaro (2018) investigated whether higher WMC would hinder insight problem-solving. Their research results suggested that WMC can benefit performance on common fundamental processes for incremental and insight problem-solving. In the study of WMC associated with Word Problem Solving (WPS), Fuchs et al. (2020) revealed that WMC contributes to individual differences in WPS. Working memory makes an important contribution to the completion of cognitive tasks, including problem-solving (Solaz-Portolés & Sanjosé-López, 2009; Wiley & Jarosz, 2012b). WMC underlies the problem-solving process and reflects differences in the control of attention to problem-solving. They claim that the key to successful problem solving is good attention control in accordance to the needs of the situation.

In this study, the observed problem solving is mathematical problem solving, examined using Polya's steps. The researchers arranged the mathematical problems by adding distracting information not relevant to the problem domain. Other studies have examined WMC concerning topics such as math ability, math anxiety, gender (H. Miller & Bichsel, 2004), IQ (Alloway & Passolunghi, 2011), and mathematical reasoning (Palengka et al., 2021). However, it is very rare to find researches that examine WMC with mathematical problem-solving based on the Polya's steps. Researches on WMC and mathematical achievement have also been carried out by Beilock and Carr (2005), Friso-Van Den Bos et al. (2013), Juniati and Budayasa (2020), and Raghubar et al. (2010), with the results showing significant positive relationship between WMC and mathematics learning achievement. Because mathematical problem solving is one of the mathematical skills students need to master, the researchers want to explore further the relationship between mathematical problem solving and WMC.

Based on the results of observations made by the researchers and the findings in the study, it was known that WMC influenced the ability to solve problems. The importance of WMC in many cognitive processes, including problem-solving, is also the background of this research. Therefore, the purpose of this research is 1) to find out the effect of WMC on mathematical abilities and 2) to describe the students' ability to solve mathematical problems based on WMC.

Methodology

The research approach used was mixed methods. Creswell (2009) defines mixed methods research as the collection, analysis, and integration of quantitative and qualitative data at several stages of the research process in one study. One of the research designs in the mixed methods research is the sequential explanatory design. The researchers first collected and analyzed quantitative (numeric) data in this design. The qualitative (text) data were collected and analyzed in the second order, and helped explain the previously-mentioned quantitative results (Ivankova et al., 2006).

In this study, the sequential explanatory design was used by the researchers. It was initiated by quantitative research to determine the effect of WMC on mathematical ability. After that, the results were analyzed. Furthermore, the research results obtained were explained in more detail using qualitative research to describe the ability of high school students in solving mathematical problems based on WMC. Through these phases, the researchers investigated further how WMC affects students' mathematical problem solving.

To answer the challenges in the design of explanatory sequential mixed methods research, the sample size used can be different for each phase of the study (Creswell, 2009). The samples of this study were high school students for the academic year 2019/2020 consisting of 58 students aged 15-17 years. After the quantitative data were collected and analyzed, the researchers obtained groups of students who were grouped according to their WMC and mathematical ability. From these groups, the researchers took one research subject from each group and conducted further investigation to obtain qualitative data.

The quantitative data collection of the WMC of the students were measured using Operation Span Tasks (OSPAN Task), and the quantitative data of mathematical ability were measured using a math test. Span tasks test a person's ability to focus on two tasks at the same time. The OSPAN, in this study, was adapted by the researchers from Turner and Engle (1989), which was also validated by a doctor in psychology. OSPAN can be accessed online at https://www.millisecond.com/download/library/categories/workingmemory by first installing IQWebPlayerSetup on your computer. The researchers also carried out online communication through englelabtaskmanager@gmail.com to obtain supporting references in the development of OSPAN and suggestions from the management team of the "Attention and Working Memory Lab," School of Psychology in Georgia. The lab that provides various instruments measuring WMC can be accessed at https://englelab.gatech.edu/.

An example of the OSPAN Task could be seen in a study by Juniati and Budayasa (2020). However, in this study, the numbers to remember were replaced with letters. The OSPAN Task was presented in the form of a power point presentation with automatic timing to display the letters that students must remember in about four seconds, followed by the completion of mathematical operations problems. Then, the letters were written on the OSPAN Task answer sheet that had been provided in about 10 seconds.

Furthermore, a qualitative descriptive study was conducted to obtain an overview of problem-solving of high school students based on WMC. One student was taken from high WMC group and also from low WMC group with regard to their mathematical ability. The researchers collected qualitative data, namely from interview transcripts and student problem-solving results, by providing mathematical problem-solving tests and conducting interviews based on the mathematical problem-solving tasks. Mathematical problem-solving tests and interview transcripts were developed by the researchers according to Polya's (1973) problem-solving stage, which was further validated by promoters and doctors in the field of mathematics. A readability test had also been carried out for the mathematical problem-solving test to determine whether students can understand the statements or information on the test questions.

The mathematical problem given is to find the probability of many newspapers of brand A with the price of IDR 5,000 and newspapers of brand B with the price of IDR 4,000, which are sold on Tuesday at Mr. Ali's kiosk. The sales results of the newspapers on Tuesday are unknown, but the sales results of newspapers on other days, along with the average sales of newspapers in a week, are known. The sales results sale of the newspapers on Monday are IDR 64,000; Wednesday IDR 66,000; Thursday IDR 75,000; Friday IDR 88,000; Saturday IDR 90,000; and Sunday IDR 90,000. Mr. Ali gives a special price for buying newspapers with a one-month subscription package, IDR 100,000 for brand A newspapers and IDR 85,000 for brand B newspapers. The number of newspapers provided at the kiosk every day is 12 copies maximum each for brand A and brand B newspapers.

Data Analysis / Technique of Data Analysis

All obtained data were analyzed using the explanatory sequential mixed methods (Ivankova et al., 2006), beginning with quantitative data analysis with quantitative descriptive techniques, followed by explanation and elaboration of quantitative findings using qualitative data collection technique. Quantitative data analysis to determine the effect of WMC on mathematical ability was carried out by applying regression analysis using SPSS software. Qualitative data, namely the results of solving mathematical problems and interview transcripts, were analyzed based on the analysis model (Miles et al., 2014), namely data reduction, data display, and conclusion drawing.

Data reduction in this study included: (1) coding the data obtained; (2) sorting or selecting data relevant to the research objectives; (3) group data according to the focus of information on the data; and (4) making a summary based on the grouped data. The researchers carried out this activity continuously until this research ended. The data were displayed in this study with narrative text. It was used to define the process and results obtained from research activities. The data were presented separately between one step and the other. Conclusions were drawn in stages, and the first was to draw up temporary findings. Still, it was necessary to verify the data with increasing data, namely by re-learning existing data. In this study, the conclusion was intended to describe the mathematical problem solving of high school students based on WMC. To check the truth of the data obtained from the respondent (subject of the study), the researchers did member checking. Birt et al. (2016) stated that member checking, also known as participant or respondent validation, is a technique for exploring qualitative research results' credibility. Data or interview results are returned to the respondent to check for accuracy and resonance with their experiences. Furthermore, the researcher compared the suitability of the research data with the meaning contained in the research problem conceptually to obtain valid data.

Findings / Results

Quantitative Research Results

58 high school students aged 15-17 years were given a math test and OSPAN Task. The followings are the results of the analysis of students' mathematical ability data obtained from math test scores and students' WMC data obtained from OSPAN Task scores.

Table 1. Descriptive Statistics of Mathematical Ability and WMC

	N	Minimum	Maximum	Mean	Std. Deviation
WMC	58	9.50	100.00	87.29	21.179
Mathematical ability	58	20.00	95.00	66.19	16.729
Valid N (listwise)	58				

a) Descriptive Statistics of Students' Mathematical Ability and WMC

In Table 1, the average mathematical ability of the students is relatively high, namely 66.19. The standard deviation, which shows the average deviation of the mathematical ability data from the average price, is 16.73. By using the standard deviation values and the average mathematical ability, it was obtained the categorization of the mathematical abilities of 58 students; there were nine students in the high mathematical ability category, 42 students in the medium mathematical ability category, and seven students in the low mathematical ability category. Analysis related to students' OSPAN Task results showed that students' average WMC was 87.28, with a standard deviation of 21.18. The average value shows that students correctly remember about 87% of the letters given in sequence while solving mathematical operations problems. Based on the quartile split technique (Conway et al., 2005) on the OSPAN Task score of 58 students, it was shown that 18 students are in the high WMC category and 14 students are in the low WMC category.

b) Effect of WMC on Mathematical Ability

Regression analysis was performed to determine the independent variable's effect (WMC) on the dependent variable (students' mathematical ability). The followings are the regression analysis results of students' WMC and students' mathematical ability using SPSS.

Table 2. Output Summary from Regression Analysis of Mathematical Ability and WMC

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.536[a]	.287	.274	14.25316

Table 3. ANOVA From Regression Analysis of Mathematical Ability and WMC ANOVA[b]

Model	Sum of Squares	df	Mean Square	F	Sig.
1 Regression	4576.377	1	4576.377	22.527	.000[a]
Residual	11376.537	56	203.152		
Total	15952.914	57			

a. Predictors: (Constant), WMC

b. Dependent Variable: Mathematical ability

Table 2 and Table 3 report that WMC and mathematical ability have a strong and significant positive relationship, indicated by Multiple R, 0.536 and a significant value of $p = 0.000 < 0.05$. A positive relationship between the students' mathematical abilities and the students' WMC means that if students' WMC increases, students' mathematical abilities also tend to increase and vice versa. R square, which is often called the coefficient of determination, measures the goodness of fit of the regression equation. The output also obtained an R square of 0.287, which indicates that the effect of the independent variable (WMC) on the dependent variable (mathematical ability) is 28.7%, while the other variables explain the rest.

Table 4. Output Coefficients from Regression Analysis of Mathematical Ability and WMC

	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	Beta	t	Sig.
1 (Constant)	29.262	8.002		3.657	.001
WMC	.423	.089	.536	4.746	.000

Dependent Variable: Mathematical ability

The standard error of 8.002 in Table 4 shows the standard error of the estimation of the dependent variable (mathematical ability). This figure is compared with the standard deviation of the mathematical ability of 16.73 (Table 1). It is found that the standard error is smaller than the standard deviation. The smaller the standard error number is compared to the standard deviation number of mathematical ability yields more precision of the regression model that predicts the mathematical ability. In Table 4, it is also known that the regression coefficient for WMC (X) is 0.423, and the regression model for Mathematical Ability (Y) is 29.262 + 0.423X with a 95% confidence level. In the regression model, it is known that the constant of 29.262 mathematically means that when the WMC is 0, the mathematical ability is equal to that constant. A scatter plot is presented below to see a more straightforward relationship between the two variables.

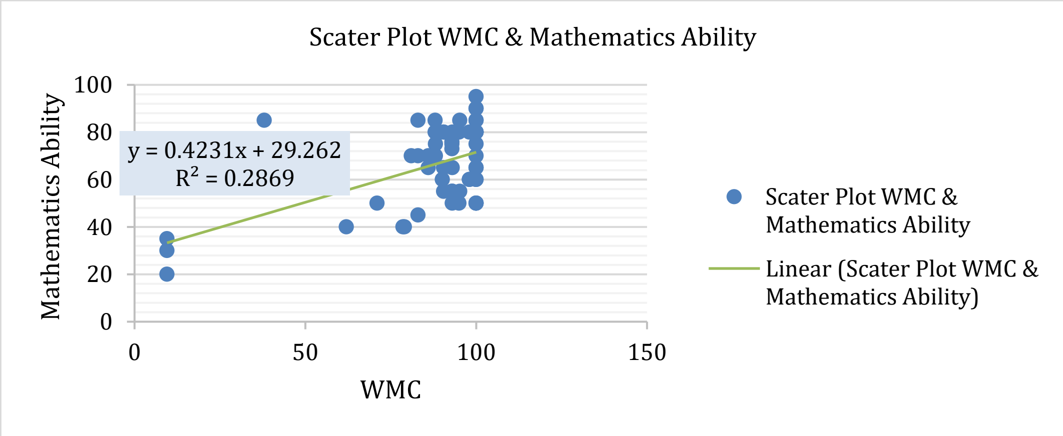

Figure 1. Scatter Plot of WMC and Mathematical Ability

The scatter plot in Figure 1 shows that the higher the value of WMC (variable X) is, the greater the mathematical ability becomes (variable Y). The two variables have a positive correlation.

Qualitative Research Results

After the researchers found the significant results that WMC had on mathematical ability, the researchers revealed more about the effect of the WMC. Based on the results of the categorization of the mathematical ability score and the OSPAN Task score, the researchers took a student from the high WMC group and a student from the low WMC group to investigate their mathematical problem solving ability. Two students were selected as research subjects by the researchers on the condition that they have different WMC and equivalent mathematical ability.

Table 5. Information on Determination of Research Subjects

No.	Subject	Gender	The Scores of the OSPAN Task (Mean=80,78)	The Category of WMC	The Scores of Math Ability Test (Mean=41,54)	The Category of Math Ability
1.	HWM	Woman	100	High	95	High
2.	LWM	Woman	38	Low	86	High

Data collection was carried out by giving mathematical problem solving tasks about determining the number of newspapers sold and interviews based on mathematical problem solving tasks. The following are the results of the problem solving analysis of the two subjects based on Polya's steps:

a) Subjects with high WMC (HWM)

1. Understanding the problem

HWM mentions all the information in the problem in full. For the information needed in solving the problem, HWM added another important information, namely the subscription price (the price of the newspaper obtained from purchasing newspapers on a one-month subscription basis). It obtains this information by describing the additional information (detractors) provided on the problem.

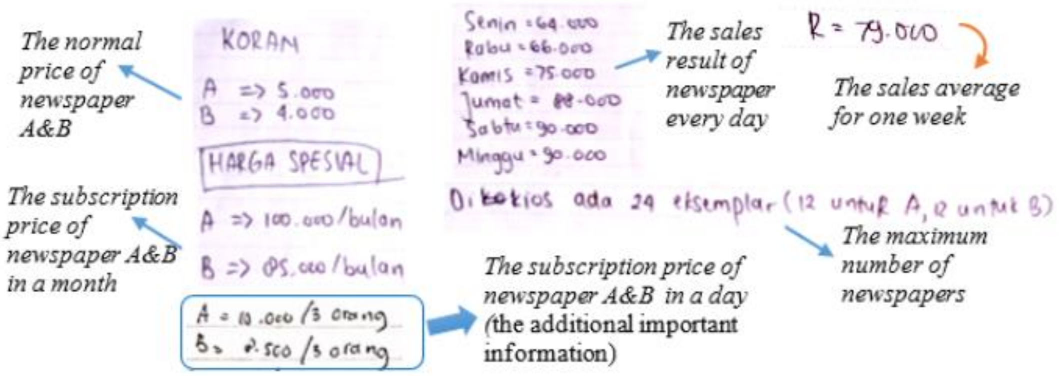

Figure 2. HWM's answer about the information in the problem

The following is an excerpt from the HWM interview regarding the steps to understanding the problem

R: *What information is needed to solve the problem?*

S: *The information needed to solve the problem are the sales average for one week and the sales results every day,ma'am.*

R: *Is there anything else?*

S: *The price of newspapers A and B also the maximum number of newspapers provided in one day are 12 copies for each newspaper.*

R: *Are those enough? Are those all the information needed to solve the problem?*

S: *Oh, with subscription price, ma'am.*

R: *Is the subscription price also a required information?*

S: *Yes, the subscription price can be used to find the number of newspapers. Maybe if we calculate the subscription price for a copy of newspaper in 1 day it is difficult, because the subscription price for 1 month is 100.000 IDR if we divide by 30 the result is 3.333,33 IDR. But the price can be rounded up, for example, there are 3 people who subscribe to the newspaper for 1 month. So 100.000 x 3 = 300.000. We can divide 300.000 by 30 and the result is 10.000 IDR per day for 3 people who subscribe to newspaper A. Likewise with newspaper B, we can get a price of 8.500 IDR per day for 3 people who subscribe to newspaper B.*

2. Devising a plan to solve the problem

The settlement plan mentioned by HWM would look for the sales results of newspapers on Tuesday. Then, she would divide it by using the normal price (the price of newspapers A = 5.000 IDR and the price of the newspapers B = 4.000 IDR) and also the sale results of newspapers on Tuesday by the combination of the normal price and the subscription price. After that, she would find more than one possible answer because she uses two different types of prices in calculating the number of newspapers, namely the normal price and the subscription price.

R: *So by this way you will find a lot of newspapers, is that your plan?*

S: *Yes, at first I only used the normal price, but later I will try to find more newspapers using the normal price combined with the subscription price.*

R: *What is the predicted answer for the possible number of newspapers?*

S: *It Can be obtained approximately more than one possibility, ma'am.*

R: *More than one possibility, why?*

S: *Because there are two ways. The first way: many newspapers are found using normal prices and the second way: many newspapers are found using subscription prices combined with normal prices.*

3. Carrying out the plan

HWM carried out the completion plan according to the plan mentioned earlier. After finding the sale results of newspapers on Tuesday, she wrote down two ways/strategies to determine the number of newspapers. The first strategy uses normal prices only and the second strategy uses normal prices combined with subscription prices, provided that the number of newspapers is not more than 12 copies each.

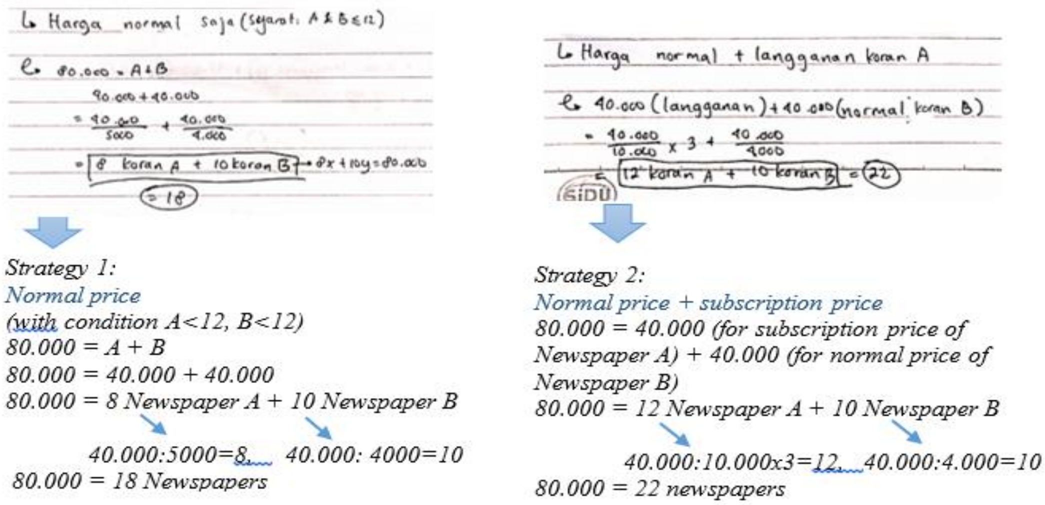

Figure 3. HWM's answer about implementation problem solving steps

In the problem-solving step that HWM implements, she also tries to enter some possible numbers to calculate. Some of the results of the number of newspaper found met the requirements and some did not meet the requirements. At the end of his experiment in entering numbers, she finally found four possible answers.

4. Looking back

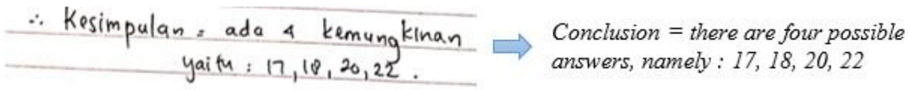

Figure 4. HWM's final answer

After carrying out the problem solving steps, HWM looked back at the answers to ensure that the calculation results were not wrong and the answers obtained met the specified requirements. She marked the answers that did not meet the requirements so as not to be included in the answer to the problem, and the four possible answers she found were written down in the conclusion.

b) Subjects with low WMC (LWM)

1. Understanding the problem

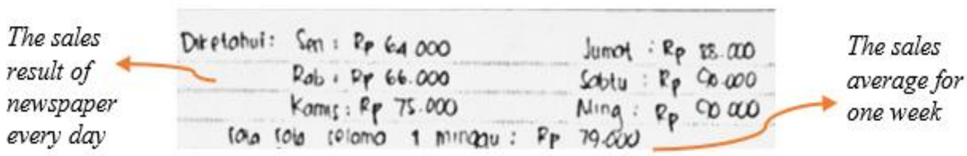

Figure 5. LWM's answer about the information in the problem

In understanding the problem, LWM did not provide complete information in the problem. For the information needed in solving the problem, there was an important information that was missed by LWM, namely the maximum number of newspapers (12) provided each day for each newspaper. The following is an excerpt from the LWM interview regarding the steps to understanding the problem.

R: To solve the problem, what information do you use?

S: I use sales results information for each day and average sales results for the week

R: What do you mean by sales result information for each day?

S: *I mean information about newspapers sales result on Mondays, Wednesdays, Thursdays, Fridays, Saturdays, and Sundays.*

R: *Are the information enough?*

S: *Not yet, there are additional information, namely the price of newspapers A and B for the unit price or per copy price, ma'am.*

2. Devising a plan for solving the problem

The problem solving plan drawn up by LWM was to find the the sales results of newspapers on Tuesday. Then, the results were divided by the unit price of the newspaper (normal price). The following is an excerpt from an interview with LWM:

R: *After knowing the information that will be used in solving the problem, then for the problem solving plan, what strategies or steps will you use?*

S: *First, I will look for the sale results of newspapers on Tuesday, Mom. After that, I divide the sales result of newspapers on Tuesday by the unit price for newspaper A = 5.000 IDR and newspaper B = 4.000 IDR*

3. Carrying out the plan

For the first step in solving the problem, LWM carried it out according to the settlement plan mentioned earlier and found the sales result of newspapers on Tuesday. However, she divided the sales result of newspapers on Tuesday into two equal amounts and then divided each nominal by the price of newspapers A or newspaper *B*.

Here are the excerpt from the interview and LWM's answers:

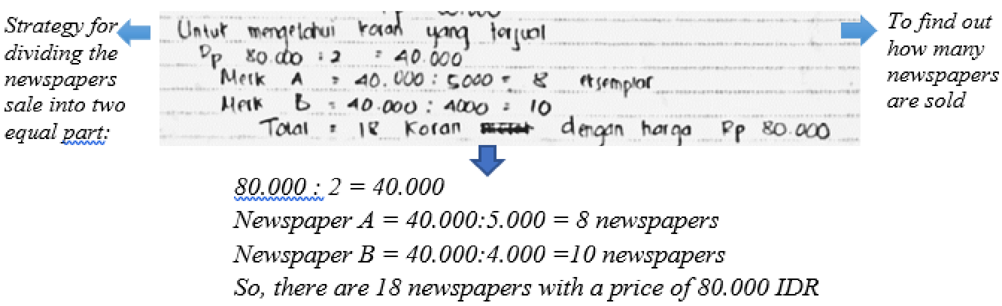

Figure 6. LWM's answer about implementation of problem solving steps problem

R: *After finding the sale results of newspapers on Tuesday, what are your next steps?*

S: *To find out how many newspapers brand A and brand B were sold, I divided 80,000 into 2 equal parts because they were even. So newspaper brand A is 40,000 and newspaper brand B is 40,000. Next, each part is divided by the unit price (normal price), 40,000:5,000=8 and 40,000:4000=10. 8 + 10=18 so the number of newspapers were sold is 18 newspapers*

4. Looking Back

After getting the answers from the results of the implementation of problem solving, LWM looked back at the answers by making sure the calculation results are correct. LWM also thought of other possible answers that complete the question.

R: *Are you sure about the answers you get?*

S: *Yes, ma'am, but there seems to be another answer. From 80.000 can be divided again into 20.000 and 60.000 then can be divided by 5 and 4.*

R: *Does this way also include possible answers to the problem?*

S: *Yes, because of that way I can also get the number of newspapers sold on Tuesdays*

R: *Then, is there any other possible answer?*

S: *Yes, there is. The other possible answer is obtained from the 60.000 and 20.000,* *the opposite of 20.000 and 60.000. So there are 3 possible answers for the number*

of newspapers sold, which obtained from 40.000 and 40.0000, 20.000 and 60.000, 60.000 and 20.000. Each value c be divided by the price of newspapers A or newspaper B.

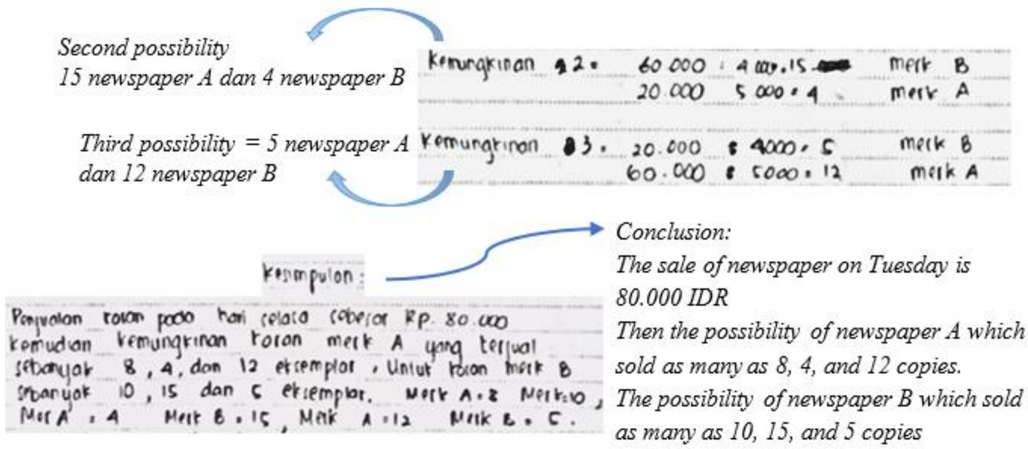

Figure 7. LWM's final answer

*B*ased on the interview excerpt and LWM's answer, it is known that LWM subdivided the sales result of newspapers on Tuesday and produced two nominals and then divided each nominal by the price of newspaper A and newspaper B, namely the requirement that the maximum number of newspapers available is 12 copies for each newspaper. Hence, there are incorrect answers that do not meet the requirements. In determining this conclusion, it appears that LWM is less thorough in re-examining the answers.

After observing the results of the presentation of the qualitative data above, at the stages of problem-solving carried out by HWM and LWM, namely understanding the problem, devising a plan to solve the problem, carrying out the plan, and looking back the problem-solving process, there are mental activities that occurs involving WMC. The mental activity is in the form of information storage, information processing, or information retrieval.

At the stage of understanding the problem, HWM and LWM mentioned the same main problem to be solved, namely determining the probability of the number of newspapers that were sold on Tuesday. However, in saying information that supports problem-solving strategies, HWM and LWM showed differences. HWM mentioned relevant information to solve problems entirely, and even he could process additional information (deceptive) into pertinent information that helps find solutions to problems. Meanwhile, LWM missed one of the relevant information that impacts finding a solution to the problem.

At the stage of devising a plan to solve the problem, both HWM and LWM used two steps of completion; the first was to find the results of Tuesday's newspaper sales, and the second step was to find the number of sold newspapers using the results of Tuesday's newspaper sales and the price of the newspapers. The researchers' finding at this stage was that the strategy proposed by HWM to solve the problem was more advanced because she was able to manipulate distracting information into relevant information with the help of mathematical operations. According to the problem domain, the distracting information being referred to here is irrelevant information that can affect students' focus in solving the problem. Meanwhile, there is only one problem-solving strategy proposed by LWM, and this strategy tends to be less advanced as it is limited only to the information she know. LWM's limitations in remembering or retrieving information from problems can cause less advanced strategies.

At the stage of carrying out the plan, HWM carried out solving strategies consistently and produce more than one possible answer according to the problem domain. While LWM, she added new steps to find solutions to problems in implementing problem-solving strategies. However, LWM ignored the suitability of the resulting solution to the problem domain.

In the stage of looking back the answers, HWM and LWM both checked the correctness of the calculations. However, in terms of accuracy, HWM were more thorough because they also checked the suitability of their answers with relevant information, while LWM did not do this, so the answers she got were wrong.

Discussion

Discussion of Quantitative Research Results.

The correlation coefficient or Multiple R = 0.536 and p value = 0.000 <0.05 obtained from the regression analysis show that there is a significant positive relationship between WMC and mathematical ability. This means that if the students'

WMC increases, the students' mathematical abilities also tend to increase. The results of this study are in line with the results of related studies that have examined the relationship between children's working memory and their learning achievement in various fields, some of which being mathematics (Alloway & Passolunghi, 2011; Friso-Van Den Bos et al., 2013; H. Miller & Bichsel, 2004) which stated that there is a relationship between working memory and mathematical achievement.

The coefficient of determination is 0.287, which means that 28.7% of the variance of Y (mathematical ability) is explained by X (WMC) in the regression model (Y) = 29.262 – 0.423X, while the rest is explained by other variables. Gathercole and Pickering (2000) stated that measuring the working memory of children who started formal education was a good predictor of reading and numeracy skills several years later. Assessment of working memory in children also provides an effective way of identifying children at risk for poor educational achievement in later years.

To see the differences in mathematical ability based on WMC, the researchers continued to investigate students with high WMC and students with low WMC by giving math problem solving tasks. The researchers monitored the process of working on mathematical problem solving tasks and conducted interviews to explore in-depth information related to the stages of solving mathematical problems.

Discussion of Qualitative Research Results.

WMC is the ability to focus on the main task and perform the necessary operations while blocking out irrelevant information (Beilock & Carr, 2005; Kane & Engle, 2000). From the results, it is known that students with low WMC miss essential information in understanding the problem and obtain solutions that are not suitable for the problem domain at the end of its completion. It can be due to the lack of ability to focus on the main task. Moreover, students with low WMC's performance decreased significantly when complexity and difficulty increase. Individuals with high WMC may have more cognitive resources to use when task complexity increases and thus are better able to deal with complex task challenges than individuals with low WMC (Ramirez et al., 2016). In line with Beilock and Carr , Wiley and Jarosz (2012a), individuals with high WMC can focus on dealing with distractions. Thus, they can better eliminate irrelevant information and focus on the task at hand.

The results showed that the strategies found by students with high WMC to solve problems were quite sophisticated/more advanced than students with low WMC. Students with high WMC can manipulate distracting information, namely information that is initially irrelevant to relevant information, with the help of mathematical operations. Students with high WMC can select several possible answers according to the problem domain. According to Wiley and Jarosz (2012b), in addition to storing and managing information that underlies the problem-solving process, WMC also reflects the control of attention (attention) in the problem-solving process. In problem-solving, superior executive function associated with high WMC. High WMC generally support more successful problem solving, and in this case, the attention control of high WMC students was quite good.

The results of our study showed that there are differences in the problem-solving process between students with high WMC and students with low WMC. Students with high WMC tend to be better at solving math problems than students with low WMC. This result in line with DeCaro (2018), higher WMC is associated with better performance on a range of tasks, including solving complex problems. A previous research Palengka et al. (2021) on mathematical reasoning conducted on students with high and low WMC also shows that there are differences in the structure of mathematical reasoning between students with high and low WMC in strategy selection and implementation of these strategies. At the strategy implementation stage, students with low WMC apply strategies in one way and cannot find maximum results. In contrast, students with high WMC can choose flexible and practical strategies and apply them in various ways to find maximum results.

Several other studies claimed that children with high WMC generally have more advanced problem-solving strategies and higher overall math achievement than children with lower WMC (Alloway & Alloway, 2010; Beilock & Carr, 2005; Ramirez et al., 2016). Thus, if difficulty in problems increases, they can use the strategies they learned during formal school to help them because students with high WMC have more cognitive resources (Ramirez et al., 2016; Wiley & Jarosz, 2012b). Furthermore, our findings also support previous studies of individuals with high WMC outperforming their lower WMC counterparts. It can be seen from high WMC students who were better at solving high complexity math problems because they had more cognitive resources for their problem approach. Students with high WMC can remember and manage more information well, which supports the determination of more advanced problem-solving strategies than students with low WMC. Students with high working memory capacity can take information from the situation or information related to mathematical concepts and use it appropriately to find a solution when given a math problem. Thus, high WMC is more helpful for students' success in solving problems (Wiley & Jarosz, 2012a).

In solving mathematical problems, WMC affects individuals in processing information on the problem by enabling the retrieval and use of domain-relevant information. WMC helps individuals achieve successful problem solving by focusing on the features of the problem and resisting distractions from irrelevant information. WMC resources affect individuals in developing knowledge related to the problem domain through integrating and encoding information into knowledge structures that support simultaneous activation in memory.

Conclusion

From the result of the initial investigation, it was found that WMC affected high school mathematics ability. Both of the variables had a significant positive correlation (R = 0.536, p-value = 0.000). We found evidence that WMC exhibits a distinct impact on mathematical ability, particularly mathematical problem-solving ability. Students with high WMC had more advanced problem-solving strategies and better attention control than students with low WMC. Students with high WMC remembered more information and could manage it well to support the determination of more advanced strategies and the discovery of appropriate problem solutions. On the other hand, students with low WMC remembered and managed information not as well as students with high WMC, seen from the missing important information from the questions and the use of imperfect problem-solving strategies. Students with low WMC experienced a decrease in attention control as the complexity of the task increased and resulted in incorrect solutions.

The results of this study are expected to provide new information about the contribution of WMC in students' mathematical problem-solving ability. As we know, the problem-solving ability is one of the mathematical abilities that needs to be mastered by students. In addition, to reveal that high WMC can be beneficial for students in supporting successful mathematical problem solving, this study also reveals that low WMC can hinder students in the mathematical problem-solving process. Therefore, teachers and researchers can consider the students' WMC in planning mathematics learning or research in mathematics education. Implementing learning or research in mathematics can, then, be an effort to train students' mathematical problem-solving abilities.

Recommendations

The findings in this study support previous researches which found that an individual's WMC plays a role in their mathematical ability. That being said, the teacher can consider the students' WMC in planning the success of students' mathematics learning. Teachers can measure students' WMC. By knowing students' WMC, it is hoped that teachers can design learning according to the characteristics, level of ability, or difficulty of the students. This learning design is related to one of the teacher's abilities in pedagogical content knowledge, namely Knowledge of Content and Students (KCS). Aspects of concern in KCS include knowledge of student characteristics and student difficulties in the learning content (Lestari et al., 2019). Teachers can take advantage of students' strengths to overcome the difficulties experienced by students (Siswono et al., 2019). On the other hand, teachers can seek learning activities that support students with low WMC to achieve better learning achievement. Teachers can also give problem-solving tasks to students as gradual exercises from simple problems to more complex problems.

Based on the findings in the study, more in-depth researches in the field of mathematical problem-solving can be carried out to explore students' difficulties, especially students with low WMC. The difficulties experienced by students with low WMC in solving mathematical problems can then be corrected or be overcome. Researches in mathematics learning by considering problem-solving or students' WMC also need to be carried out to explore learning steps that can facilitate the learning achievements of both students with low WMC and high WMC. One of the lessons that can be considered is cooperative learning because this learning can be used to increase participation and practical problem-solving in the classroom (Barczi-Veres, 2022). To find out the contribution of WMC more broadly in mathematics education, future researches may explore on WMC related to other topics such as critical thinking, creative thinking, and other mathematical abilities.

Limitations

In this study, WMC was only seen for its effect on mathematical ability, especially problem-solving. However, some researchers on WMC say that WMC has an essential role in various cognitive activities. Therefore, further researches are needed to develop this kind of research. Researches involving WMC and other cognitive activities shall provide more information about the importance of WMC

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Authorship Contribution Statement

Anjariyah: Concept and design, data acquisition, data analysis, drafting manuscript. Juniati: Concept and design, critical revision of manuscript, interpretation, and supervision. Siswono: Concept and design, critical revision of manuscript, interpretation, and supervision.

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