

Research Article

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An Analysis of Students' Commognition with Low Working Memory Capacity in Solving Calculus Problems

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Abstract

Background/purpose. This study analyzes the commognition of students with low Working Memory Capacity (WMC) when solving calculus problems, particularly in integral material. Commognition, which merges cognition and communication, is explored through four indicators: keywords (stating knowns and unknowns), visual mediators (graphical representations), endorsed narratives (use of formulas and definitions), and routines (drawing conclusions). Understanding these indicators helps reveal the thinking patterns and communication breakdowns students experience in mathematical problem-solving.

Materials/methods. This study employed a qualitative descriptive method involving 62 (20 men and 42 women) undergraduate students of mathematics education from a State Islamic University in Makassar, Indonesia. Two instruments used were the Complex Span Task (CST) to measure students' working memory capacity and the Calculus Problem Test (CPT) to evaluate problem-solving performance in Calculus, especially integral material. The instrument CST was modified by the researcher from the original instrument before use.

Results. Students with low working memory capacity struggle to meet commognition indicators: determining what is known and asked (keywords), making graphs (visual mediators), applying formulas (endorsed narratives), and drawing conclusions (routines). These difficulties highlight significant cognitive impacts and the importance of tailored instructional strategies to support mathematical understanding.

Conclusion. The study concludes that students with low WMC have difficulty in solving calculus problems, especially on integral material, namely difficulty in determining what is known and asked (keywords), making graphs (visual mediators), applying or using the correct formula (endorsed narratives), and drawing conclusions (routines). These difficulties emphasize the significant impact of limited WMC on both cognitive function and mathematical communication.

1. Introduction

Understanding how students solve mathematical problems requires attention not only to what they know but also to how they express and process that knowledge. In higher education, many students—particularly those with cognitive limitations—struggle with solving abstract mathematical problems. One contributing factor is low Working Memory Capacity (WMC). Students with low WMC often find it difficult to retain information while simultaneously processing new concepts, which negatively impacts their performance in problem-solving, especially in calculus integration problems (Baddeley, 2021; Broadway & Engel, 2022).

This study addresses a central issue: how students with low WMC manage the cognitive and communicative demands of solving calculus problems. In traditional assessments, student performance is often evaluated solely based on final answers, without considering how they think or articulate their reasoning throughout the problem-solving process. However, students with limited WMC may know what steps to take but fail to express their thinking clearly or sequentially. This mismatch between knowledge and expression can lead to misinterpretation of their understanding (Alloway & Alloway, 2020).

To address this issue, this research analyzes students' mathematical communication using the theory of *commognition*—a term introduced by Anna Sfard, which merges “cognition” (mental processes) and “communication” (verbal or written expression). For example, when a student silently reflects, “I need to apply substitution here,” they are essentially engaging in self-communication. Similarly, when a student writes down a formula or explains a step to a peer, they are turning internal thinking into interpersonal communication. Thus, thinking and talking about mathematics are not separate activities but rather two manifestations of the same process (Sfard, 2023).

Sfard's discourse-based framework provides four indicators to assess mathematical thinking: keywords (identifying known and unknown information), visual mediators (graphs or diagrams supporting conceptual understanding), endorsed narratives (correct use of definitions and formulas), and routines (stepwise patterns used to reach conclusions). These indicators form the analytical foundation of this study. By using them, researchers can trace the extent to which students express and navigate their thinking while solving integration problems (Berger, 2021; Nardi, 2022).

The purpose of this study is to investigate how a student with low WMC fulfills (or fails to fulfill) these *commognition* indicators while solving integration problems. Unlike studies that focus only on outcomes, this research offers a more nuanced view by exploring the *process* of mathematical problem-solving. Through test results and interview analysis, the study highlights communication patterns that reflect the students' internal reasoning, mathematical terminology usage, and application of problem-solving steps (Goos, 2021).

The significance of this study lies in its practical implications for mathematics education, particularly for students with diverse cognitive profiles. By understanding where communication breakdowns occur—whether in identifying given data, drawing visualizations, or concluding solutions—educators can design more effective instructional strategies. For example, teachers can explicitly model how to state knowns and unknowns, use diagrams to support reasoning, or scaffold procedures through guided questioning. These approaches help bridge the gap between thinking and communicating (Wichelt & Kearney, 2022; Kaur, 2020).

Ultimately, this research is guided by the main question: *How does a student with low working memory capacity exhibit commognitive behavior in solving calculus problems?* By applying Sfard's framework directly to observed problem-solving processes, the study provides insight into how cognitive limitations affect mathematical discourse. In doing so, it reinforces the importance of

viewing communication not as a separate skill, but as an integral part of mathematical thinking and learning (Sfard, 2023; Elias, 2021).

2. Literature Review

2.1. Commognition

Sfard's perspective on learning is known as the "commognitive framework," where the term "commognition" emphasizes the close relationship between "cognition" and "communication" (Sfard, 2023). This paradigm refers to the combination of individual thinking and interpersonal communication, illustrating that these two processes are different manifestations (intrapersonal and interpersonal) of the same phenomenon. In this context, "thinking is defined as the individualized version of interpersonal communication as a communicative interaction in which one person plays the roles of all interlocutors," meaning that thinking is a form of individualized interpersonal communication (Sfard, 2023).

According to Vygotsky, knowledge, concepts, and higher mental functions are the result of culture, constantly modified through collective human efforts. He sees language as a tool for developing thought. Within the context of mathematics learning, the similarities between Wittgenstein's and Vygotsky's theories suggest that learning mathematics can be facilitated through meaning and language in social discourse. Learning does not solely occur within an individual's mind or external to the individual but also is the result of the relationship between the individual and the social world (Danoebroto, 2021). Moreover, communication is a crucial element in every learning process (Wichelt & Kearney, 2022). In classroom activities, communication helps identify students' abilities by describing their understanding of the material being studied and providing assistance for those who experience difficulty (Berger, 2021).

Communication also supports students in developing mathematical understanding and sharpening their cognitive skills (Kaur, 2020). When students are challenged to think and communicate their thoughts, they often lack clarity and make numerous errors (Goos, 2021). Many students struggle to express terms and use words when explaining mathematical definitions systematically. Such communication difficulties are believed to stem from differences in students' thought processes during high school and university (Manolio, 2023).

Based on the explanation above, cognition and communication provide students with opportunities to develop their understanding in learning mathematics. Both factors play a significant role in children's success in the learning process, as most learning activities are always related to understanding and problem-solving. This understanding encompasses mastering facts, concepts, principles, and procedures, which are components of the cognitive domain in learning objectives.

Sfard further explains that "cognition is a form of individualized communication activity," implying that cognition is not merely an individual process separate from communication actions, nor does it always have to be interpersonal. Under this paradigm, the cognitive process and interpersonal communication process are essentially the same phenomenon (Elias, 2021).

"Commognition is a participatory theory, where learning only occurs through an individual's thoughtful engagement in mathematical discourse," which can be interpreted to mean that commognition is essentially a theory of participation because it only emerges through individual involvement in mathematical discourse (Berger, 2021). Sfard (2023) stated that "mathematics is a multilayered recursive structure of discourses-about-discourse," because mathematics is autopoiesis, which means it can create itself. Furthermore, Sfard explains that "the different types of communication, and thus of commognition, that draw some individuals together while excluding others will be called discourses." In other words, different types of communication are referred to as discourses (Nardi, 2022).

Based on the various aforementioned views, it can be concluded that commognition is a combination of thinking (individual cognition) and communication (interpersonal), which can be conceptualized as communication between a person and themselves as well as within a group.

2.2. Working Memory Capacity

Working memory is said to be a key component in most cognitive processes (Solso et al., 2008). Humans utilize various components for thinking, often referred to as memory. According to Santrock (2020), thinking involves manipulating or transforming information stored in memory. Additionally, memory allows individuals to access past experiences to use them in the present (Sternberg, 2021). It serves as a system that stores past experiences for present use.

The concept of working memory, introduced by Baddeley in 1974, remains widely utilized by scholars today. Prior to this, Atkinson and Shiffrin's model had explained short-term memory and gained prominence for its comprehensive view of memory processing (Sternberg, 2021). As for working memory itself, it is mainly understood as a domain-specific component responsible for managing attention and processing tasks such as retrieving long-term information (Miyake & Shah, 2020). Defined as a limited capacity system, it temporarily stores and manipulates information necessary for cognitive tasks like reasoning, learning, and comprehension (Baddeley in Gazzaniga, 2022). Essentially, working memory also acts as a cognitive resource for performing mental operations and recalling short-term results (Stillman, 2020).

Working memory can also be described as a cognitive system that facilitates access to information needed for ongoing mental activities (Baddeley, 2021). Its ability to retain and process information while completing cognitive tasks is integral to problem-solving (Absatova, 2023). Relating this to education, tasks involving working memory require simultaneous information recall and processing, defining it as a dynamic system for supporting reasoning and problem-solving (Cowan, 2020).

The capacity of working memory is determined by the speed of rehearsal (Baddeley, 2021). Unlike short-term memory, which focuses on temporary storage, working memory encompasses both storage and processing. It comprises interrelated components that incorporate temporary information storage and manipulation (Miyake & Shah, 2020; De Neys, 2022). Moreover, human cognitive activities heavily rely on working and long-term memory, which function together. Long-term memory serves as a repository for new knowledge and skills, while working memory manages incoming information (Clark, 2020).

In educational settings, students frequently depend on working memory for various tasks (Baddeley, 2023). Deficiencies in working memory lead to struggles with basic tasks, such as remembering instructions, and complex ones that involve storing and processing data (Daneman, 2021). Working memory is limited in both duration and capacity, with Miller (1956) suggesting its capacity ranges from seven $\pm$ two units.

Students' difficulties in memory and computation often stem from low working memory capacity (Alloway & Alloway, 2020). Stillman (2020) highlights its limited capacity as a constraint on information processing. Moreover, cognitive demands during problem-solving activities directly impact attention and working memory use. Working memory capacity is crucial across fields like education, psychology, and neuropsychology, where it underpins executive functions and problem-solving (Broadway & Engel, 2022; Willey & Jarosz, 2021).

Overall, working memory capacity reflects an individual's ability to retain and process information for tasks such as reasoning, learning, and problem-solving. It can be assessed using complex span tasks, which test the ability to focus on multiple tasks simultaneously (Hicks, 2022). These tasks, widely accepted as measures of working memory, predict various aspects of higher-

order cognition (Copeland, 2020). In addition, the essential feature of these tasks is managing interference between task components (Conway et al., 2021). For this study's purpose, working memory capacity was categorized into high and low levels.

2.3. Math Problem Solving and Commognition Indicator

Mathematical problem solving is a fundamental skill in mathematics education, involving stages such as understanding the problem, planning a solution, executing strategies, and evaluating the results (Clark, 2020). These stages require both cognitive control and conceptual fluency, particularly in calculus, where abstract reasoning and procedural fluency are essential.

Students with low Working Memory Capacity (WMC) often struggle with problem solving due to limited ability to hold and manipulate information. Challenges arise in recalling formulas, following multi-step procedures, or integrating symbolic and visual data (Baddeley, 2021; Daneman, 2021). These cognitive limitations affect not only accuracy but also the fluency of mathematical reasoning.

From a commognitive perspective, problem solving is not only a mental process but also a discursive activity. Students must express their understanding through language by identifying knowns and unknowns, justifying steps, and concluding logically (Sfard, 2023). These communicative acts reflect how students internalize and participate in mathematical discourse (Berger, 2021).

The four commognition indicators—keywords, visual mediators, endorsed narratives, and routines—align with key components of problem solving. Difficulties in any of these areas may indicate cognitive strain or discursive gaps. Therefore, analyzing students' problem-solving behavior through Sfard's framework provides deeper insights into both their thinking and communication challenges, especially for learners with low WMC.

2.3.1. Commognition Indicator

Commognition indicators according to Sfard (2023) are as follows.

Table 1. Commognition Indicators According to Sfard

Commognition Indicators	Description
1. Keywords	- Using terms in mathematics - Using special words - Writing known and asked
2. Visual Mediator	Using mediators in the form of graphs, diagrams
3. Endorsed narratives	- Using definitions - Using Theorems and Proofs
4. Routines	Generalizing, concluding, or estimating the answers obtained
a. Eksplorations	- Carrying out construction that produces a new supporting narrative - Carrying out substantiation to decide whether to support the previously constructed narrative - Recalling to the ability to recall previous narratives
b. Deed	Performing actions that are easy to do because of the patterned sequence of actions
c. Rituals	Performing socially oriented repetitive patterns

3. Methodology

3.1. Study Design

This study employed a qualitative descriptive research design, aiming to analyze how students with low Working Memory Capacity (WMC) demonstrate commognitive behavior in solving calculus problems, particularly in the area of integrals. The approach allows for in-depth exploration of cognitive and communicative patterns observed through students' problem-solving processes and interviews.

3.2. Study Population

The population of this study consisted of 62 undergraduate students (20 male and 42 female) enrolled in the Mathematics Education program at a State Islamic University in Makassar, Indonesia. These students participated voluntarily and were currently studying integral calculus material.

3.3. Study Sample

From the total population, two students were selected as research subjects using purposive sampling based on four criteria:

1. Having either a high or low score on the Working Memory Capacity test.
2. Demonstrating prior knowledge of integral calculus concepts.
3. Possessing sufficient communication skills to participate in interviews.
4. Agreeing to maintain the confidentiality of their identity.

The study focused specifically on one student, coded as SP01, who exhibited low working memory capacity based on the test results. The other student (SP02, with high WMC) was not analyzed further in this study.

Table 2. Determination of Research Subjects

Student Initials	Scores		CST Category	Label
	CST	CPT		
N	27	55	Low	SP01
MY	83	91	Hight	SP02

3.4. Instruments

Two main instruments were used in this study:

1. Complex Span Task (CST) to measure students' working memori capacity
2. Calculus Problem Test (CPT) to evaluate problem-solving performance in Calculus especially on integral material

The instrument CST was modified by the researcher from the original instrument before use, and permission was obtained from the original instrument maker. Both instruments were validated by three associate professors in mathematics education and had been validated in terms of content and feasibility, scoring 3.85 and 3.90, respectively (maximum score: 4.00). The difficulty level of the instruments was classified as moderate, with scores of 0.751 and discrimination coefficients of 0.672 for the first instrument, and scores of 0.85 and discrimination coefficients of 0.79 for the second instrument. Based on empirical tests, both instruments met validity criteria with coefficients of 0.854 and 0.891. Reliability tests using Cronbach's Alpha ($\alpha = 5\%$) indicated that both instruments were reliable, with coefficients of 0.811 and 0.794, respectively. The instrument trials were conducted on

ten students from a private university in Enrekang Regency, Indonesia, yielding difficulty indices of 0.784 and 0.733, and discrimination coefficients of 0.677 and 0.751.

Both instruments were validated and deemed appropriate for data collection. Subsequently, sixty-two students were given the Complex Span Task. Two days later, students were categorized into high and low working memory capacity groups based on the test results. Following this classification, students worked on the Integral Problem Test questions for 120 minutes under direct supervision by the researcher, assisted by a lecturer in charge of the course.

3.5. Data Analysis and Coding Procedure

After collecting data from the CPT and the follow-up interviews, the analysis was conducted in several systematic steps as follows:

1. Transcription of written responses and interview data from the selected participant (SP01).
2. Identification and coding based on the four commognition indicators: *Keywords, Visual Mediators, Endorsed Narratives, Routines*
3. Evaluation and interpretation of each indicator using both written evidence and verbal explanations.

To make the analysis process more systematic and traceable, an analysis flowchart was developed to illustrate the stages from data collection, coding, to interpretation (see Digram 1). This diagram helps trace how data from each participant is linked to cognitive indicators and facilitates cross-validation between test and interview results.

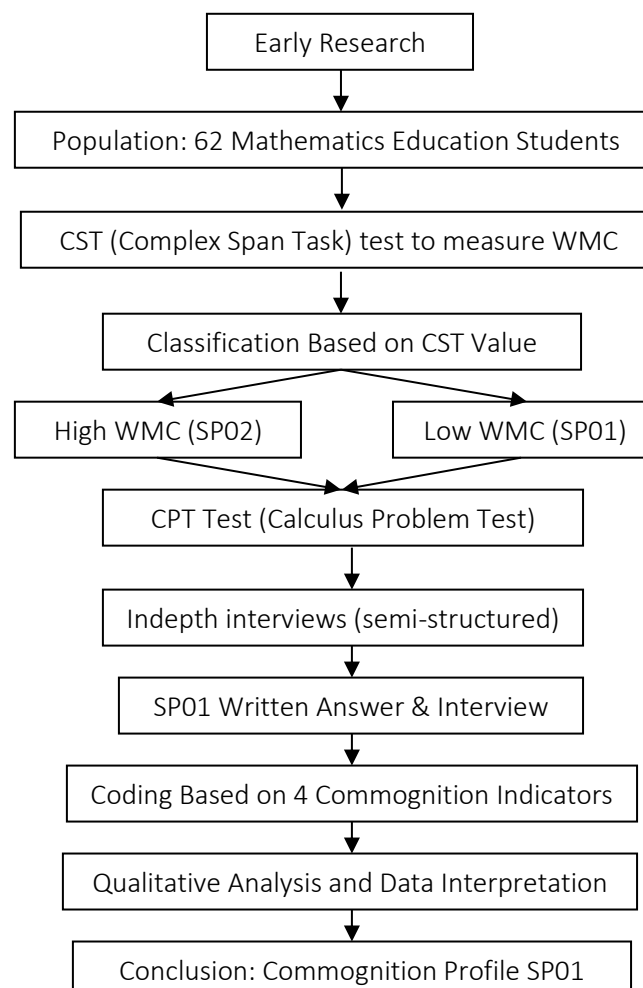


Diagram 1. Flowchart Participant Selection and Analysis Strategy

4. Results

The commognition of selected research subjects with the initials N labelled as SP01 (a student with low Working Memory Capacity) is presented in this section through the results of doing the Calculus Problem Test (CPT) questions, especially on integral material.

The questions given are as follows:

1. Tentukan hasil dari $\int \frac{t^2 \cos^2(t^3-2)}{\sin^2(t^3-2)} dt$!

1. Determine the result of $\int \frac{t^2 \cos^2(t^3-2)}{\sin^2(t^3-2)} dt$

Figure 1. Question Number 1

As shown in Figure 1, the first question was about solving integration technique problems with substitution. The research subject was asked to find the indefinite integral result by substitution. As depicted in Figure 2, the following is the answer from the SP01.

Figure 2. SP01's Answer to Question Number 1

Based on the test and interview results, the subject was observed to be able to work on the question correctly. However, based on Figure 2, the subject did not meet the *comprehension indicators of keywords*, as evidenced by the SP01 research subject's failure to write what was known and what was asked in question number 1. Nevertheless, the SP01 subject was able to show and explain when interviewed. This was in accordance with the statement made by the subject when interviewed, as shown in Table 3.

Table 3. Transcription of Interview with Subject SP01 Regarding Achievement of the *Commognition Indicator of Keywords* for Question Number 1

P/SP01	Interview Transcription
P	Can we start the interview?
SP01	Yes, sir.
P	Okay. What is known and what is ordered or asked from question number 1?
SP01	The known information is $\int \frac{t^2 \cos^2(t^3 - 2)}{\sin^2(t^3 - 2)} dt$
P	Okay. So, what was ordered or asked?
SP01	The result of

$$\int \frac{t^2 \cos^2(t^3 - 2)}{\sin^2(t^3 - 2)} dt$$

In question number one, the *communication indicator of visual mediator* is not discussed because in working on question number 1, it is not necessary to draw a graph or diagram first.

Furthermore, from the answer of subject SP01 to question number 1, it can be seen that subject SP01 could fulfill the *commognition indicator of endorsed narratives*. This could be viewed from the subject's ability to use the existing formula to work on question number 1. However, subject SP01 could not fulfill the *commognition indicator of routines*, which can be seen from the answer of subject SP01 who did not conclude the answer obtained. However, subject SP01 could show and explain during the interview. This was in accordance with the statement made by the subject during the interview, as seen in Table 4.

Table 4. Transcription of Interview with SP01 Regarding Achievement of the *Commognition Indicator of Routine* for Question Number 1

P/SP01	Interview Transcription
P	What conclusion can you write from the answers you get?
SP01	The question is number one, sir.
P	
SP01	So, the result of $\int \frac{t^2 \cos^2(t^3 - 2)}{\sin^2(t^3 - 2)} dt$ that is $-\frac{1}{3}(\cot(t^3 - 2) + (t^3 - 2)) + C$

The results of SP01's answer and response to question number 2 is presented below. The question can be seen in Figure 3.

2. Tentukan hasil dari $\int \sin^4 x \, dx$!.

2. Determine the result of $\int \sin^4 x \, dx$

Figure 3. Question Number 2

Question number 2 was about solving several trigonometric integral problems. The research subject was asked to find the indefinite integral result of trigonometry. Figure 4 shows the subject's answer to the question.

$$\begin{aligned}
 2. \quad \int \sin^4 x \, dx &= \int \sin^2 x \cdot \sin^2 x \, dx \rightarrow \int \sin^2 x \cdot (1 - \cos^2 x) \, dx \\
 &= \int \sin^2 x \, dx - \int \sin^2 x \cos^2 x \, dx \\
 \sin^2 x &= \frac{1}{2} - \frac{1}{2} \cos 2x \\
 \sin^4 x &= \left(\frac{1}{2} - \frac{1}{2} \cos 2x\right) \left(\frac{1}{2} - \frac{1}{2} \cos 2x\right) \\
 &= \frac{1}{4} - \frac{1}{4} \cos 2x - \frac{1}{4} \cos 2x + \frac{1}{4} \cos^2 2x \\
 &= \frac{1}{4} - \frac{1}{2} \cos 2x + \frac{1}{4} \cos^2 2x \\
 \Rightarrow \int \sin^4 x \, dx &= \int \left(\frac{1}{4} - \frac{1}{2} \cos 2x + \frac{1}{4} \cos^2 2x\right) dx \\
 &= \int \left(\frac{1}{4}\right) dx - \int \left(\frac{1}{2} \cos 2x\right) dx + \int \left(\frac{1}{4} \cos^2 2x\right) dx \\
 &= \frac{1}{4} x - \frac{1}{4} \sin 2x + \frac{1}{4} \int (1 + \cos 4x) dx \\
 &= \frac{1}{4} x - \frac{1}{4} \sin 2x + \frac{1}{8} x + \frac{1}{32} \sin 4x + C \\
 &= \frac{3}{8} x - \frac{1}{4} \sin 2x + \frac{1}{32} \sin 4x + C
 \end{aligned}$$

Figure 4. SP01 Student's Answer to Question Number 2

Based on the test and interview results, it shows that in general, the subject could work on question number 2 correctly. However, based on Figure 4, the subject did not meet the *commognition indicator of keywords*. This can be verified from the answer of the SP01 research subject, who did not write what was known and what was asked in question number 2, but he was able to show and explain them during the interview. This is in accordance with the statement made by the subject during the interview, as shown in Table 5.

Table 5. Transcription of Interview with Subject SP01 Regarding Achievement of the *Commognition Indicator of Keywords* for Question Number 2

P/SP01	Interview Transcription
P	What is known and what is ordered or asked in question number 2?
SP01	The known information is $\int \sin^4 x \, dx$ While the question asked one is: The result of $\int \sin^4 x \, dx$

In question number 2, the *communication indicator of the visual mediator* is not discussed because it is not necessary to draw a graph or diagram first.

Furthermore, from the answer to the subject SP01, it can be seen that subject SP01 could fulfill the *commognition indicator of endorsed narratives*. This can be checked from SP01's ability to utilize the existing formula to work on question number 2. However, subject SP01 could not fulfill the *recognition indicator of routines*, as viewed from the answer of subject SP01, who could not conclude the answer obtained, but he could show and explain during the interview. This is in accordance with the statement made by the subject during the interview, as shown in Table 6.

Table 6. Transcription of Interview with Subject SP01 Regarding Achievement of the *Commognition Indicators of Routine* for Question Number 2

P/SP01	Interview Transcription
P	What conclusion can you write from the answers you get?
SP01	So the result of $\int \sin^4 x \, dx$ that is $\frac{3}{8}x - \frac{1}{4}\sin 2x + \frac{1}{32}\sin 4x + c$

3. Garis g menyinggung kurva $y = \sin x$ di titik $(\pi, 0)$. Jika daerah yang dibatasi oleh garis g, garis $x = \frac{1}{2}\pi$ dan kurva $y = \sin x$ diputar mengelilingi sumbu X. Hitunglah volume benda putar yang terjadi !.

3. Line g touches the curve $y = \sin x$ at the point $(\pi, 0)$. If the area bounded by line g, line $x = \frac{1}{2}\pi$ and the curve $y = \sin x$ is rotated around the X-axis. Calculate the volume of the rotating object that occurs!

Figure 5. Question Number 3

Question number 3, as shown in Figure 5, was about solving several trigonometric integral problems, namely calculating the volume of a rotating object. The research subject was asked to find the volume of a rotating object rotated around the x-axis. Figure 6 illustrates the answer from the SP01 research subject to the question.

3. Dik. $y = \sin x$
 $y' = \cos x$
 $y'(x) = \cos(x) = 1$
 $g: y = -1(x - \pi)$
 $g: y = -x + \pi$

Jawab:
 Volume = $\pi \int_{\pi/2}^{\pi} (\sin^2(x) - (-x + \pi)^2) dx$

$= \pi \left[\int_{\pi/2}^{\pi} \left(1 - \frac{1}{2}(\cos(2x) + 1) \right) dx + \int_{\pi/2}^{\pi} (-1)(-x + \pi)^2 dx \right]$
 $= \pi \left[\frac{x}{2} - \frac{1}{2} \left(\frac{x}{2}(-\sin(2x)) + \sin(x) \right) + \frac{x}{2} \right] +$
 $\frac{1}{2} (0^2 - (\pi/2)^2)$
 $= \pi \left[\frac{x}{2} - \frac{x}{4} - \frac{x^3}{24} \right]$
 $= \frac{\pi^2}{2} \left[\frac{1}{2} - \frac{\pi^2}{12} \right]$
 $= \frac{\pi^2}{4} \left[1 - \frac{\pi^2}{6} \right] = V = \frac{6\pi^2 - \pi^3}{24}$

Figure 6. SP01 Student's Answer to Question Number 3

The test and interview results show that subject SP01 could not answer question number 3 correctly. Based on Figure 6, the subject was only successful in fulfilling *the commognition indicator of keywords* seen from the answer that the subject gave. The subject could not write what was known from the question correctly and did not write what was asked or ordered from question number 3 to be done. Meanwhile, when the interview was conducted, SP01 still had a little difficulty writing what was known and what was asked from the question. Table 7 illustrates the transcript of the interview with SP01 regarding this matter.

Table 7. Transcription of Interview with Subject SP01 Regarding Achievement of the *Commognition Indicator of Keywords* for Question Number 3

P/SP01	Interview Transcription
P	What do you know from question number 3 and what is asked in question number 3?
P	What is the known information first?
SP01	The known information is curve $y = \sin x$ at point $(\pi, 0)$
P	Why that sentence? What's the sentence before it?
SP01	(Stay silent)
P	What is the position of line g?
SP01	Oh, yes, sir. Line g touches the curve $y = \sin x$ at point $(\pi, 0)$
P	Ok, good. So, what?
SP01	If the region is bounded by line g, line $x = 1/2 \pi$, and curve $y = \sin x$, it is rotated around the X-axis.
P	So, what is the question?
SP01	The volume of rotating objects that occurs!

Furthermore, from the answer of subject SP01 to question number 3, it can be seen that subject SP01 could not fulfill the *comprehension indicator of visual mediator*, as seen from the answer of subject SP01 to question number 3, which could not describe the graph based on what was known from the question. Likewise, when the interview was conducted, subject SP01 had difficulty

describing the graph based on what was known from the question. Table 8 shows an interview with subject SP01 regarding this matter.

Table 8. Transcription of Interview with Subject SP01 Regarding Achievement of *the Commognition Indicators of Visual Mediator* for Question Number 3

P/SP01	Interview Transcription
P	a graph or picture from the question?
SP01	(Confused about where to start drawing it)
P	Do we have to make a diagram?
SP01	(Fall silent)
P	Cartesian first. Try to make a Cartesian diagram first.
SP01	(Make a Cartesian diagram on the paper provided.)
P	Determine which x-axis and which y-axis!
SP01	(Determine the x and y axes of the created Cartesian diagram.)
P	Ok. Good. What's next?
SP01	(Confused)
P	In the Cartesian diagram, create a curve of sin x!
SP01	Sin x curve, sir?
P	Yes
SP01	(Confused)

From the answer of subject SP01 to question number 3 in Figure 6, it can be seen that subject SP01 failed to fulfill *the communication indicator of endorsed narratives*, observed from the answer of the subject to question number 3 that showed the subject's inability to use the existing formula or was wrong in using the existing formula to calculate the volume of the rotating object correctly. To calculate the volume of the rotating object, subject SP01 should have used the formula.

$V_x = \pi \int_a^b [h^2(x) - g^2(x)] dx$ with $h(x) = (-x + \pi)$ dan $g(x) = \sin x$, so that the volume of the rotating object is: $V_x = \pi \int_{\frac{1}{2}\pi}^{\pi} [(-x + \pi)^2 - (\sin x)^2] dx$. However, subject SP01 used the formula $V_x = \pi \int_a^b [h^2(x) - g^2(x)] dx$ with $h(x) = \sin x$ and $g(x) = (-x + \pi)$, so that the volume of the rotating object was: $V_x = \pi \int_{\frac{1}{2}\pi}^{\pi} [(\sin x)^2 - (-x + \pi)^2] dx$. Likewise, when interviewed, subject SP01 had difficulty in calculating the volume of the rotating object. Table 9 depicts the transcription of an interview with subject SP01 regarding this matter.

Table 9. Transcription of Interview with Subject SP01 Regarding the Achievement of the *Commognition Indicators of Endorsed Narratives* for Question Number 3

P/SP01	Interview Transcription
P	Using the definitions, theorems, and proofs that you know, work on question number 3!
SP01	(Fall silent)
P	What is the formula for finding the volume of a rotating object?

SP01	Square root (<i>Mentioning anything</i>)
P	V equals?
SP01	(<i>Fall silent</i>)

From the answer of subject SP01 in Figure 6, it can be seen that subject SP01 also did not fulfill *the commognition indicators of routines*. This can be seen from subject SP01, who was unable to correctly conclude the answer obtained.

4. Buktikan rumus berikut:

$$\int x^a \ln x \, dx = \frac{x^{a+1}}{a+1} \ln x - \frac{x^{a+1}}{(a+1)^2} + C, a \neq -1$$

4. Prove the following formula:

$$\int x^a \ln x \, dx = \frac{x^{a+1}}{a+1} \ln x - \frac{x^{a+1}}{(a+1)^2} + C, a \neq -1$$

Figure 7. Question Number 4

As seen in Figure 7, question number 4 was about solving integration technique problems with partial integrals. The research subject was asked to prove an indefinite integral result using partial integrals. Figure 8 shows the answer from the SP01 research subject on the given question.

Handwritten solution for Question 4:

$$\begin{aligned} 4. \text{ Misal } u &= \ln x & dv &= x^a \, dx \\ du &= \frac{1}{x} \, dx & v &= \frac{x^{a+1}}{a+1} \\ \int u \, dv &= u \, v - \int v \, du \\ &= \ln x \cdot \frac{x^{a+1}}{a+1} - \int \frac{x^{a+1}}{a+1} \cdot \frac{1}{x} \, dx \\ &= \frac{x^{a+1}}{a+1} \ln x - \frac{1}{a+1} \int x^a \, dx \\ &= \frac{x^{a+1}}{a+1} \ln x - \frac{1}{a+1} \cdot \frac{x^{a+1}}{a+1} + C \\ &= \frac{x^{a+1}}{a+1} \ln x - \frac{x^{a+1}}{(a+1)^2} + C \quad (terpilih) \end{aligned}$$

Figure 8. Subject SP01's Answer to Question Number 4

Based on the test and interview results, it shows that in general, subject SP01 could do question number 4 correctly. Based on Figure 8, the subject did not meet the *comprehension indicator of keywords*, as evidenced by the SP01 research subject's answer, which did not include what was known and what was asked in question number 4. Nevertheless, subject SP01 was able to show and explain them during the interview. This is in accordance with the statement made by the subject during the interview as shown in Table 10.

Table 10. Transcription of Interview with Subject SP01 Regarding Achievement of the *Commognition Indicator of Keywords* for Question Number 4

P/SP01	Interview Transcription
P	What do you know from question number 4 and what is asked or ordered in question number 4 for you to do?
P	What is the known information?
SP01	It is

$$\int x^{\alpha} \ln x \, dx = \frac{x^{\alpha+1}}{\alpha+1} \ln x - \frac{x^{\alpha+1}}{(\alpha+1)^2} + C, \alpha \neq -1$$

P So, what do you need to do?

SP01 Prove the formula

In question number 4, the *communication indicator of visual mediator* is not discussed because in working on question number 4, it is not necessary to draw a graph or diagram first.

Furthermore, from the answer of subject SP01 from question number 4, it can be seen that subject SP01 could fulfill the *commognition indicators of endorsed narratives*. This can be seen from the subject's ability to use the existing formula to work on question number 4. However, subject SP01 could not fulfill the *commognition indicators of routines*. This can be observed from the answer of subject SP01 which did not conclude the answer obtained, but he could still show and explain it during the interview. This is in accordance with the statement made by the subject during the interview as shown in Table 11.

Table 11. Transcription of Interview with Subject SP01 Regarding Achievement of the *Commognition Indicators of Routine* for Question Number 4

P/SP01	Interview Transcription
P	What conclusion can you write from the answers you get?
SP01	In conclusion, it is proven that $\int x^{\alpha} \ln x \, dx = \frac{x^{\alpha+1}}{\alpha+1} \ln x - \frac{x^{\alpha+1}}{(\alpha+1)^2} + C, \alpha \neq 1$

5. Dengan menggunakan metode dekomposisi pecahan parsial, tentukan hasil dari

$$\int \frac{x^3 - 4x}{(x^2 + 1)^2} \, dx$$

5. Using the partial fraction decomposition method, determine the result of

6. $\int \frac{x^3 - 4x}{(x^2 + 1)^2} \, dx$

Figure 9. Question Number 5

As illustrated in Figure 9, question number 5 was about solving several integral problems of rational functions. The research subject was asked to solve integral problems with the integration of rational functions. Figure 10 presents the answer from the SP01 research subject.

$$\begin{aligned} 5. \quad \frac{x^3 - 4x}{(x^2 + 1)^2} &= \frac{Ax + B}{x^2 + 1} + \frac{Cx + D}{(x^2 + 1)^2} \\ x^3 - 4x &= (Ax + B)(x^2 + 1) + (Cx + D) \\ x^3 - 4x &= Ax^3 + Ax + Bx^2 + B + Cx + D \\ x^3 - 4x &= Ax^3 + Bx^2 + (A + C)x + B + D \\ \text{Sehingga diperoleh} \\ A &= 1 \quad B = 0 \quad C = -5 \quad D = 0 \\ \text{Maka,} \\ \int \frac{Ax + B}{x^2 + 1} + \frac{Cx + D}{(x^2 + 1)^2} &= \int \frac{1x + 0}{x^2 + 1} + \frac{-5x + 0}{(x^2 + 1)^2} \\ &= \int \frac{x}{x^2 + 1} + \int \frac{-5x}{(x^2 + 1)^2} \, dx \end{aligned}$$

Figure 10. SP01's Answer to Question Number 5

The test and interview results show that subject SP01 could not answer question number 5 correctly. Based on Figure 10, the subject failed to fulfill the *commognition indicators of keywords*. This fact is clearly seen from the answer of the SP01 research subject, who could not write what was known from the question correctly, and did not write what was asked in question number 5. However, he was able to show and explain them when interviewed. This is in accordance with the statement made by the subject during the interview, as shown in Table 12. The following is a transcript of the interview with SP01 regarding this matter.

Table 12. Transcription of Interview with Subject SP01 Regarding Achievement of the *Commognition Indicator of Keywords* for Question Number 5

P/SP01	Interview Transcription
P	What is known from question number 5 and what is asked for you to do?
P	It was known that
	$\int \frac{x^3 - 4x}{(x^2 + 1)^2} dx$
P	What was asked?
SP01	Determine the result of $\int \frac{x^3 - 4x}{(x^2 + 1)^2} dx$ by using the partial fraction decomposition method

In question number 5, the *communication indicator of visual mediator* is not discussed because in working on question number 5, it is not necessary to draw a graph or diagram first.

Furthermore, from the answer given by the subject as depicted in Figure 10, it can be seen that subject SP01 could not fulfill the *commognition indicators of endorsed narratives*, similar to the previous questions. This can be seen from subject SP01's inability to use the existing formula to work on question number 5 correctly. The subject could only work on parts of question number 5 correctly. Furthermore, the subject could not fulfill the *cognitive indicators of Routines*, which can be seen from the answer of subject SP01, who could not conclude the answer obtained.

6. Sebuah tangki berbentuk kerucut lingkaran tegak diisi penuh dengan air. Jika tinggi tangki 7 meter dan jari-jari lingkaran atas 3 meter, tentukanlah kerja yang diperlukan untuk memompa air (a) melewati tepi atas tangki, dan (b) mencapai 7 meter di atas puncak tangki!. (Kerja = Gaya . Jarak atau $W = F \cdot d$ dan kerapatan/berat air (δ) = 1000 kg/m^3).

(6.) A tank in the shape of a right circular cone is completely filled with water. If the height of the tank is 7 meters and the radius of the top circle is 3 meters, determine the work required to pump the water:

(a) over the top edge of the tank, and

(b) to a height of 7 meters above the tip of the tank.

Figure 11. Question Number 6

As illustrated in Figure 11, question number 6 was about solving problems related to the application of integrals in everyday life. The research subject was asked to solve the problem of the

application of integrals in everyday life, namely the work required to pump water (a) past the top edge of the tank, and (b) reaching 7 meters above the top of the tank. However, it is to be known that SP01 did not answer the question, but when an interview was conducted about question number 6, SP01 was able to correctly state what was known from question number 6 and what was asked in question number 6. It can be seen that subject SP01 had no difficulty in fulfilling the *commognition indicators of keywords*. Table 13 shows the results of the interview regarding this matter.

Table 13. Transcription of Interview with Subject SP01 Regarding Achievement of the *Commognition Indicator of Keywords* for Question Number 6

P/SP01	Interview Transcription
P	What is known from question number 6 and what are you asked or ordered to do from question number 6?
SP01	It is known: • A tank in the shape of a right circular cone is completely filled with water • The height of the tank is 7 meters • The radius of the upper circle is 3 meters
P	Good. Then what was asked or ordered?
SP01	Determine the work required to pump water (a) past the top of the tank, and (b) to 7 meters above the top of the tank!

Next, the *commognition indicator of the visual mediator*, the subject could not be observed in this question, as the subject did not attempt to answer the question. In addition, during the interview, subject SP01 was also unable to mention the steps taken to draw the graph for question number 6. Table 14 illustrates the results of the interview regarding this matter.

Table 14. Transcription of Interview with Subject SP01 Regarding the Achievement of the *Communication Indicators of Visual Mediators* for Question Number 6

P/SP01	Interview Transcription
P	How to make a graph and use it for question number 6?
SP01	(Fall silent)
P	Try drawing a cone-shaped cylinder first!
SP01	(Confused)
P	Can you?
SP01	No, sir.
P	Ok.

Furthermore, the *commognition indicators of Endorsed Narratives* also could not be observed as the subject did not do the task. In addition, when interviewed, subject SP01 was also unable to explain the work on question number 6 using the existing definition, formula, or proof. Subject SP01 should be able to explain that if an object moves a distance along a line, while the object is subjected to a

constant force F in the same direction as the direction of motion of the object, then the work W done by the force is "Work = (Force). (Distance)" or $W = F.d$

Based on the formula, the work was continued so that the final result was obtained, namely the work required to pump water (a) past the top edge of the tank, and (b) reaching 7 meters above the top of the tank. Shown in Table 15, the following are the results of the interview regarding this matter.

Table 15. Transcription of Interview with Subject SP01 Regarding the Achievement of the *Commognition Indicators of Endorsed Narratives* for Question Number 6

P/SP01	Interview Transcription
P	Using the definitions, formulas, theorems, and proofs that you know, work on question number 6!
SP01	(Fall silent)
P	In the question, the formula has been determined. Let's see what the formula is?
SP01	Work = (Force). (Distance) Or $W = F . d$
P	Okay. Next, if you already know the formula, what are the next steps?
SP01	(Fall silent)
P	How?
SP01	Don't know sir

From question 6, it can be seen that subject SP01 also could not fulfill the *commognition indicators of routine* because subject SP01 did not work on the question. This was reinforced during the interview where subject SP01 could not correctly conclude or estimate the answer. The following are the results of the interview regarding this matter, illustrated in Table 16.

Table 16. Transcription of Interview with Subject SP01 Regarding Achievement of the *Commognition Indicators of Routine* for Question Number 6

P/SP01	Interview Transcription
P	What conclusion can you write from the answers you get?
SP01	Cooperation with force times distance, sir.
P	Eh, that's the formula for finding work.
SP01	(Confused)
P	How?
SP01	Don't know sir

5. Discussion

This study has examined the commognitive behavior of a student with low working memory capacity (WMC) when solving Calculus problems especially on integral material, focusing on their

performance across four commognition indicators: keywords, visual mediators, endorsed narratives, and routines. The findings revealed significant disparities in the ability to meet these indicators, shedding light on the challenges faced by students with low WMC in mathematical problem-solving.

The results showed that students with low WMC, represented by the subject SP01, encountered substantial difficulties in fulfilling most of the commognitive indicators, particularly in tasks requiring complex cognitive processing. For instance, while SP01 demonstrated partial success in achieving the word use indicator, especially during guided interviews, there was a consistent inability to independently articulate known and requested information within the problem statements. This aligns with previous research suggesting that limited WMC adversely affects the ability to organize and retrieve information effectively (Alloway & Alloway, 2020).

SP01 also faced challenges in meeting the visual mediator indicator, as evidenced by the subject's difficulties in constructing graphical representations and diagrams. These findings corroborate recent studies highlighting the reliance on effective mathematical communication in the integration of visual tools (Wichelt & Kearney, 2022). The absence of accurate visual mediators underscores the limitations in cognitive resource allocation, which is often constrained in individuals with low WMC.

In terms of Endorsed Narratives, the subject showed limited proficiency in applying formulas and constructing coherent mathematical arguments. While some tasks were completed correctly with direct guidance, the inability to independently derive or verify results points to a fragmented understanding of the underlying mathematical concepts. This finding is consistent with Sfard's (2023) assertion that cognitive and communicative processes are interdependent and that deficits in one domain can hinder overall mathematical discourse.

The Routines indicator posed the most significant challenge for SP01. The subject's inability to generalize or conclude solutions highlights a disconnect between problem-solving steps and their logical integration into cohesive outcomes. This aligns with the theoretical framework suggesting that WMC plays a crucial role in maintaining intermediate results while simultaneously processing new information (Broadway & Engel, 2022).

These findings carry profound implications for educational practices aimed at supporting students with low WMC. First, the development of targeted interventions emphasizing scaffolded instruction and structured problem-solving routines could mitigate some of the observed difficulties. Educators might benefit from incorporating explicit teaching of visualization techniques and guided discourse to strengthen students' abilities in visual mediators and endorsed narratives.

Second, fostering metacognitive strategies such as self-questioning and reflection may enhance students' capabilities to fulfill the Routines indicator. Such strategies could aid in bridging the gap between intermediate steps and final conclusions, thereby improving overall mathematical reasoning and communication.

While this study provides valuable insights into the commognitive behaviors of students with low WMC, its scope is limited by the sample size that focuses on a single representative subject. Future research should explore these phenomena across diverse populations and incorporate longitudinal designs to better understand the developmental trajectory of commognitive skills.

Additionally, investigating the role of technological tools and adaptive learning platforms in supporting commognition could offer innovative solutions to address the specific needs of students with low WMC. By tailoring interventions to individual cognitive profiles, educators can foster more inclusive and effective learning environments.

These findings are in line with previous research conducted by Alloway and Alloway (2020), who also found that individuals with low WMC struggle to organize and retrieve mathematical information effectively. Similarly, Berger (2021) and Goos (2021) emphasized the role of discourse in mathematics

learning and noted that students with limited cognitive resources tend to underperform in expressing their mathematical reasoning. The difficulty SP01 experienced with visual mediators also resonates with Wichelt and Kearney's (2022) observation that students with low WMC often fail to translate abstract mathematical expressions into visual representations.

Furthermore, the inability of SP01 to consistently apply correct formulas and reach conclusions independently aligns with Broadway and Engel's (2022) findings on the role of WMC in fluid reasoning and multi-step problem-solving. Compared to students with high WMC analyzed in prior studies, SP01 exhibited greater fragmentation in reasoning and required more interviewer support to complete routines, confirming the interdependence between cognitive capacity and communicative fluency proposed by Sfard (2023).

Thus, this study reinforces and extends earlier research by providing in-depth qualitative evidence from real problem-solving situations, highlighting how limitations in WMC manifest not only in performance outcomes but also in the observable stages of mathematical communication.

6. Conclusion

This study has comprehensively examined how students with low Working Memory Capacity (WMC) engage in solving calculus problems, especially on integral material, through the lens of commognition, a framework that merges cognitive and communicative processes. Focusing on a representative subject, the research highlighted consistent challenges in meeting commognition indicators, including the use of keywords, visual mediators, endorsed narratives, and routines. Students with low WMC have difficulty in solving calculus problems especially on integral material, namely difficulty in determining what is known and asked from the problem (keywords), making graphs of what is known from the integral problem (visual mediators), applying or using the correct formula (endorsed narratives) and drawing conclusions from the results of working on the integral problem (routines). These difficulties emphasize the significant impact of limited WMC on both cognitive function and mathematical communication. The findings suggest a strong need for educational strategies that cater to such cognitive limitations. Future research should extend these insights by examining broader and more diverse student populations, and exploring the role of adaptive technologies in supporting mathematical discourse and inclusivity in learning environments.

6.1. Limitations and Suggestions for Future Research

This study has several limitations that should be acknowledged. First, the analysis focused on a single student (SP01) with low working memory capacity, which limits the generalizability of the findings. While the case study approach allows for in-depth exploration, it does not capture the full range of variability among students with similar cognitive profiles. Second, the research was conducted within a specific institutional and cultural context in Indonesia, which may influence students' mathematical communication styles and problem-solving approaches. Third, although interviews were used to validate students' written responses, the reliance on self-reporting may introduce bias or inaccuracies in capturing real-time cognitive processes.

For future research, it is recommended to expand the participant pool to include a more diverse and representative sample of students, both in terms of working memory capacity levels and educational backgrounds. Comparative studies involving students with high WMC may provide richer insights into the specific challenges faced by students with cognitive limitations. Additionally, longitudinal research could explore how commognitive indicators develop over time and how targeted interventions impact students' mathematical communication. Finally, future studies may benefit from integrating technological tools—such as eye-tracking or digital problem-solving environments—to more precisely capture cognitive and communicative patterns during problem-solving.

Declarations

Author Contributions. Conceptualization, R.A, Y.F. and M.; methodology, R.A. and Y.F.; formal analysis, R.A.; writing—original draft preparation, R.A.; writing—review and editing, R.A., Y.F. and M.; supervision, R.A., Y.F., M. All authors have read and agreed to the published version of the manuscript.

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