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Embodied Cognition in an OSNK Mathematics Olympiad Winner: Geometry vs. Algebra Problem Solving

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***Abstract*:**
This study aims to describe the characteristics of embodied cognition that emerge when a high school student who won the District-Level National Science Olympiad (OSNK) in Mathematics solves an Olympiad-level geometry and algebra problem. This study adopts a qualitative descriptive case study design involving an 11th-grade student who won the 2025 OSNK Mathematics competition. Data were collected through synchronized video–audio recordings capturing gestures, utterances, and written problem-solving processes, as well as reflective interviews and analysis of the subject's answer sheets. The research tasks consisted of two problems: one geometry problem and one algebra problem derived from authentic Olympiad materials. Data validity was ensured through triangulation across video observations, written work, and interview data. The data were analysed using the interactive analysis model proposed by Miles, Huberman, and Saldaña, including data reduction, data display, and conclusion drawing, supported by a systematic coding process for embodied cognition indicators. The findings indicate that the subject's embodied cognition was manifested through the integration of gestures and utterances across all stages of problem-solving, except during looking back. Writing gestures appeared most dominantly in geometry and algebra problems as a means of organizing information, planning strategies, and executing solutions. Representational gestures were more apparent in geometry problems to aid visualization of shapes and spatial relationships, while pointing gestures appeared more contextually to emphasize important parts of the solution. From the utterance perspective, variations in tone of voice, facial expressions, gaze direction, and body posture functioned to support focus, clarify steps, and reflect the subject's confidence or doubt during thinking. These findings highlight that solving high-level mathematical problems occurs through the simultaneous integration of verbal and nonverbal process. Theoretically, this research enriches the study of embodied cognition in mathematics education, particularly for high-ability students. Practically, the results suggest that mathematics teachers and Olympiad coaches should attend to students' gestures and utterances as indicators of mathematical thinking processes rather than focusing solely on final answers

Keywords: embodied cognition, gesture, utterance, cognitive adaptability, OSNK student.

Introduction

Mathematics plays a fundamental role in various aspects of modern life, making mathematical problem-solving an essential competency that students must develop. In mathematics education, problem solving is commonly conceptualized as a process of overcoming challenging situations to achieve goals that cannot be reached directly. One of the mos widely adopted frameworks for mathematical problem solving is

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Polya's four-stage model, which consists of understanding the problem, devising a plan, carrying out the plan, and looking back (Polya, 1983).

Traditionally, mathematical problem solving has often been viewed as a purely mental activity that occurs within the mind, detached from bodily processes. However, the process of solving mathematical problems is often viewed as an activity that occurs entirely in the mind, is abstract, and separate from the body. This view has come under criticism in recent studies that show the body plays a crucial role in supporting the process of thinking and learning mathematics (Tran et al., 2017). This bodily involvement can be understood through the perspective of embodied cognition, namely the view that thinking is not separate from the body but is integrated with the individual's physical experience, movement, responses, and interactions with the environment (Goldinger et al., 2016). Thus, when students draw, point, move their hands, adjust their intonation, or focus their gaze while solving problems, these actions are not merely additional behaviors, but rather part of an ongoing cognitive process. In the study of embodied cognition, understanding of abstract concepts is not only built through mental activity but is also rooted in the individual's physical experiences. This means that the body, mind, and environment work together to shape mathematical understanding (Abrahamson & Bakker, 2016). Body movement can help activate both spatial and symbolic representations, thereby strengthening students' conceptual understanding (Kersey et al., 2024).

In general, embodied cognition encompasses two main aspects: gesture and utterance. Thus, embodied cognition can be observed in students' gestures and utterances during the process of solving mathematical problems (Dwijayanti et al., 2019). Gesture can be seen as a facilitator that helps and supports the process of solving mathematical problems. According to Dwijayanti et al., (2019), in the context of mathematics, gestures are divided into three types: pointing gestures, representational gestures, and writing gestures. Another form of embodied cognition that can be displayed in the process of solving mathematical problems is through utterances. Utterance is the dialogue used to manifest mathematical imagination from the results of a person's thought process, such as facial expressions, gaze, and eye movements, tone of voice, and body composure (Nemirovsky & Ferrara, 2009). Utterances play a crucial role because they can demonstrate a person's emotions, beliefs, or level of understanding when faced with a systemic problem. Furthermore, gestures are an inseparable part of speech (Dwijayanti et al., 2019). This shows that the brain's thought process gives rise to internal imagination, and for that imagination to be realized and understood in real terms, a physical manifestation through embodied cognition is required. Embodied cognition begins with imagination, while imagination itself requires a form of embodiment in its measurement (Da Rold, 2018). This embodiment can be displayed by each student in their own way.

Various studies have shown that embodied cognition plays a crucial role in understanding complex mathematical concepts. In geometry, students tend to use representational gestures, such as drawing triangles or indicating the direction of rotation with their hands, because geometry requires visualization of objects and spatial relationships (Schindler et al., 2025). In contrast, in algebra material, which emphasizes more symbolic and procedural manipulation, the dominant gestures are writing and pointing gestures when students write equations or trace relationships between symbols (Kokushkin & Tech, 2020). In addition, gaze direction and eye movements have been shown to be related to students' focus and symbolic understanding when solving algebraic problems (Kokushkin & Tech, 2020). In addition, utterances such as gaze direction and eye movements have also been shown to be related to students' focus and symbolic understanding when solving algebraic problems (Paskovske & Kliziene, 2024). These findings indicate that the form of embodied cognition is strongly influenced by the nature of the mathematical material students encounter.

However, previous studies still have several limitations. Many studies have discussed gestures and utterances separately, thus not providing a complete picture of how the two relate to each other in representing students' mathematical thinking processes (Kelly et al., 2015). In fact, in problem-solving practice, body movements and verbal and nonverbal expressions appear simultaneously and complement each other. Furthermore, most embodied cognition research is still conducted with students of average or general ability, so little is known about how embodied cognition patterns emerge in high-ability students, especially those who win the district- or city-level National Science Olympiad (OSNK) in high school. This limitation is important because high-achieving students are thought to have more reflective, structured, and strategic thinking patterns, thus potentially demonstrating different and more integrated embodied cognition characteristics than students in general (Zuo & Wang, 2023); (Callahan, 2018). In contrast, research on low-ability students shows that the gestures that emerge tend to be less directed and more random (Shinta & Wahidin, 2022). This comparison shows that students' ability level likely influences the quality of integration between gestures, utterances, and the mathematical ideas being processed.

Research gap this also lies in the context of the material and cognitive demands. Geometry and algebra problems have different epistemic characteristics. Geometry is visual-spatial and requires the ability to imagine shapes and spatial relationships, while algebra is symbolic-procedural and emphasizes the systematic manipulation of symbols. Although several studies have shown differences in the forms of gestures in the two materials, studies that specifically examine the characteristics of gestures and utterances and their relationship in high school OSNK winning students when solving geometry and algebra problems are still very limited, especially in the context of Indonesian mathematics education (Nurfadilah & Afriansyah, 2022). In fact, in complex problem-solving situations that require high-level strategies, gestures and utterances are thought to emerge not only as spontaneous responses but also as cognitive strategies to manage thought load, maintain focus, and emphasize important steps (Journal Of Medives ; Ma'allaili et al., 2024). Thus, this research is directed at answering the following questions: the characteristics of gestures and utterances of OSNK SMA winning students when solving geometric and algebraic mathematical problems, and the relationship between gestures and utterances in presenting their mathematical thinking processes.

Based on the research gap identified above, this study aims to describe how do gestures and utterances characterize and interact in representing the mathematical thinking processes of an OSNK-winning student during geometry and algebra problem solving. This study focuses on an OSNK-winning student to provide an in-depth analysis of gesture–speech interactions that reflect embodied mathematical thinking in advanced problem solvingThis study is expected to provide theoretical and practical contributions. Theoretically, this study enriches the study of embodied cognition in mathematics education, especially in the context of high-ability students and geometry and algebra materials. Practically, the results of this study can be a basis for teachers and OSN supervisors to pay more attention to students' physical-expressive aspects, such as gestures, gaze direction, intonation, and body composure, as part of the mathematical thinking process, rather than only focusing on the final results of students' work.

Research Methods

This research uses a qualitative descriptive approach. This approach was consistently chosen because the research focused on a specific, bounded case: the emergence of embodied cognition in a high school student who won the district- and city-level National Science Olympiad (OSNK) in geometry and algebra. Qualitative case studies are appropriate because they allow researchers to explore in depth the relationship between gestures, utterances, and the subject's mathematical thinking process in a natural context, without manipulating variables (Levitt et al., 2018). Thus, the purpose of this study is not to make statistical generalizations, but rather to gain a rich and in-depth understanding of embodied cognition patterns in high-ability subjects.

The research subject was one 11th-grade student who was the winner of the 2025 Jember Regency level National Science Olympiad (OSN) in Mathematics. This subject was chosen because he is one of the outstanding students who not only won the OSNK, but also frequently won in various mathematics competitions, such as the Matriks Competition UIN KHAS Jember, DETIK MSC UNEJ, PEMNAS 2024, and so on, and has even been a finalist at the district/provincial OSN level several times since junior high school. These characteristics indicate that the subject has high mathematical abilities, experience solving non-routine problems, and thinking strategies that are thought to be more structured, reflective, and complex than those of students in general. The use of a single subject in this study is based on a research orientation that emphasizes depth of data rather than generalizing from the number of participants. Therefore, the subject is considered capable of providing rich data to describe the characteristics of embodied cognition in solving high-level mathematical problems.

The research was conducted in three stages: preparation, implementation, and data analysis. In the preparation stage, the researcher focused on two main components of embodied cognition: gesture and utterance. The questions used consist of two questions: one geometry question and one algebra question, taken from the original OSN Mathematics scripts from previous years without changing their form, context, or level of difficulty. The use of original questions is intended to maintain the authenticity of the mathematical context and provide a working situation that approximates competition conditions (Balai Pengembangan Talenta Indonesia, 2023). Both questions were also guaranteed to have never been worked on by the subjects before, so the solutions they provided truly reflected the thought processes and strategies that emerged naturally.

During the implementation phase, subjects were asked to solve both problems individually in a school laboratory with adequate lighting and a comfortable seating position. Subjects' activities were recorded using two high-resolution digital mobile phones. The first device was aimed at the subjects' faces and upper bodies to capture facial expressions, head movements, and body composure, as well as the process of writing, drawing, and completing the problem-solving steps (Seccia & Goldin-Meadow, 2024). A second device was placed in the subject's pocket to record their voice from beginning to end. Recordings were conducted simultaneously to allow for synchronous observation of gesture and utterance data. During the task, subjects were given a time limit to maintain a competitive atmosphere without excessive pressure, allowing gestures and utterances to emerge naturally.

After completing the task, the researcher conducted reflective interviews to confirm the meaning of specific gestures and utterances that emerged during the problem-solving process. The interviews focused on key moments in the recordings, such as when the subject pointed to a specific area, changed tone of voice, touched their head, drew, or displayed a specific expression. These interviews aimed to strengthen the researcher's interpretation of the observational data.

The main instrument in this research is the researcher, who plays a role in determining the research focus, collecting data, observing, coding, and interpreting the research results (Miles et al., 2020). The supporting instruments included two digital mobile phones, question sheets, answer sheets, and interview guidelines. Data collected included video recordings, speech transcripts, facial expressions, gaze direction, body movements, written work, and observation notes. Data were analyzed using an interactive analysis model Miles et al., (2020), which includes data reduction, data presentation, and drawing conclusions. In the data reduction stage, the researcher repeatedly rewatched the entire video recording, then selected sections relevant to the emergence of embodied cognition. The selected data was then transcribed and grouped according to Polya's four stages of problem-solving: understanding the problem, planning a solution, implementing the plan, and reviewing. After that, the coding process was carried out on the gestures and utterances that emerged.

Coding was performed by marking video clips, transcripts, and observation results that showed the emergence of embodied cognition indicators, then grouping them based on indicator type, Polya stage, and question type. The coding categories used refer to the embodied cognition indicators, as shown in Table 1 below.

Table 1. Embodied Cognition Indicator

No.	Indikator Embodied Cognition	Kode	Deskripsi
1.	Pointing Gesture	PG	The gesture of pointing at an object around you usually uses the index finger of thumb.
	Representational Gesture	RG	Hand movements representing shapes , objects, or spatial relayionship
	Writing Gesture	WG	The movement of writing a statement or object either on paper or imaginary in the air. (Dwijayanti et al., 2019)
2.	Facial Expressions	FE	Includes facial expressions used in communicating, showing emotions, or responding to a message.
	Gaze and Eye Movement	GEM	Shows that the person is in the process of thinking and shows a form of confirmation of belief and self-confidence.
	Tone of Voice	TV	The tone of voice can indicate a person's level of confidence in each statement delivered.
	Body Calmness	BC	A calm body posture shows confidence in one's statement, while an uneasy posture shows difficulty in dealing with something. (Nemirovsky & Ferrara, 2009)

Each indicator occurrence was coded by type, then analyzed according to Polya's stage and the problem type (geometry or algebra). The coded data were then presented in narrative descriptions, interview excerpts, tables, and visual documentation to demonstrate the patterns of gesture and utterance occurrence and their relationships to the subjects' mathematical thinking processes.

Data validity is maintained through data triangulation (Denzin, 2017). Triangulation was conducted by comparing and connecting data obtained from video observations, subject answer sheets, and reflective interviews. In this way, each finding was not based solely on a single data source but was verified through multiple sources to enhance the credibility and consistency of the research results. As the primary reference in observing the problem-solving process, the two questions used in this study are shown in Figure 1

Figure 1. Question Instruments

Results

In this section, the researcher presents the results of the analysis of the subjects' embodied cognition in solving OSN mathematics problems based on Polya's four problem-solving stages, understand the problem (T.1), devise a plan (T.2), carry out the plan (T.3), and look back (T.4). Polya's stages are used to organize the data so that the emergence of gestures and utterances at each stage can be systematically identified. Data were obtained through observation of answer sheets, documentation of subjects' behavior while solving OSN mathematics problems, and interviews, all of which were reviewed from an embodied cognition perspective.

a. Understanding the Problem Stage (T.1)

The following are the results of observations from the answer sheets and the subjects' embodied cognition at the stage of understanding the problems in geometry questions.

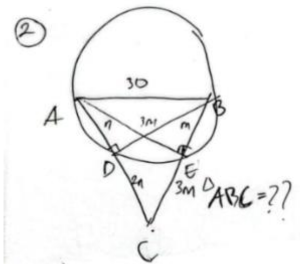


Figure 2. Subject Answer Sheet for T.1 Geometry Questions

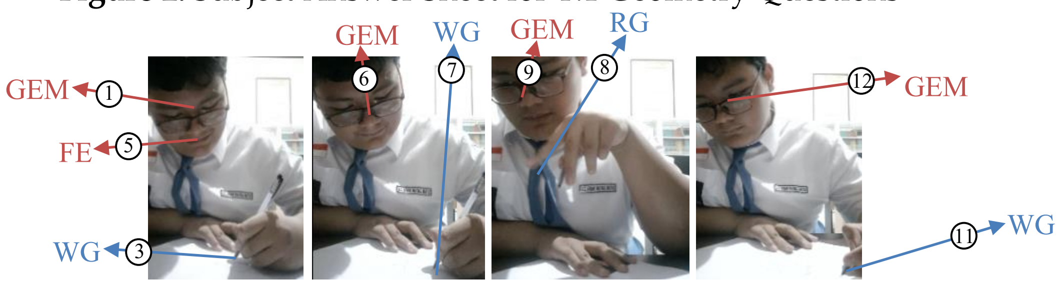


Figure 3. Eye Gaze, Writing Gestures, Facial Expressions, and Subject Representational Gestures in T.1

Based on Figures 2 and 3, two main forms of gestures are visible at the problem understanding stage: writing gestures and representational gestures. Writing gestures are seen when the subject draws a composite plane figure and writes down known and requested information. Meanwhile, representational gestures appear when the subject rotates a finger in the air to imagine a circle, then moves it horizontally and vertically to represent the length of a side. In terms of utterance, the subject shows changes in tone of voice, facial expression, and eye gaze direction. The tone of voice sounds firmer when reading important information, then softens as the subject begins to imagine the shape and relationships among the elements in the problem. Facial expressions appear relaxed with a smile, while eye gaze alternates between the problem and the answer sheet.

The following is an interview excerpt at the stage of understanding the problem.

S : *At the initial stage, what did you do to make it easier to solve question number 1?*

P : *First, I read and understand the question, then use my fingers to rotate and imagine the shape of the circle and move my fingers left and right to imagine the length of the sides. After that, I draw the combined flat shape and write down the known and unknown information using variables m and n.*

S : *During the process, what was your goal in using the changing tone of your voice, your smile, and your gaze focused on the question and answer sheet?*

P : *The high and low tones of my voice were to emphasize the length of the sides, while my smile indicated that I understood the question and was confident that I could answer it. Yes, my gaze was focused on the question so that I could write the answer on the answer sheet according to the question.*

Based on observations and interviews, it can be inferred that, at the problem-understanding stage, embodied cognition serves as a means of constructing an initial representation of the problem. Representational gestures not only accompany explanations but also help subjects visualize geometric elements that are not yet fully present in symbolic form on the answer sheet. On the other hand, writing gestures demonstrate an effort to structure visual understanding. The shift in gaze between the question and the answer sheet indicates a process of coordination between external information and the representation being constructed, while changes in tone of voice signal an emphasis on information deemed important. Thus, at this stage, embodied cognition facilitates visualization, information selection, and the structuring of an initial understanding of the problem.

b. Solution Planning Stage (T.2)

The following are the results of observations from the answer sheets and the subjects' embodied cognition during the planning stage of solving geometry problems.

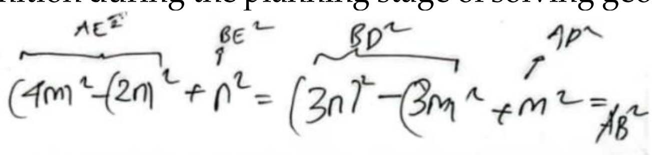


Figure 4. Subject Answer Sheet for T.2 Geometry Questions

Figure 5. Writing Gestures, Facial Expressions, Eye Gaze, and Body Posture of Subjects in T.2

In Figures 4 and 5, embodied cognition during the solution-planning stage is evident in the dominance of writing gestures as the subject begins to construct equations based on the concept of similar triangles and the Pythagorean theorem. In terms of his utterance, his voice sounds very low; his facial expression shows momentary confusion; and his gaze is mostly focused on the answer sheet, with occasional returns to the drawing he has made. Furthermore, his body posture appears tense, as evidenced by subtle head movements.

The following is an interview excerpt at the completion planning stage.

P	:	*What steps will you plan to continue solving the problem?*
S	:	*After drawing the diagram, it can be seen that there is a right angle, so the next step is to write and calculate using the Pythagorean theorem to obtain the equation (shown in Figure 4).*
P	:	*Earlier, you seemed confused while holding your head and speaking in a low voice. Was there a problem, and what did that mean?*
S	:	*It wasn't a problem. I just blanked out for a moment and tried to understand it again by looking at the questions and pictures on the answer sheet. However, after that, I continued to focus on completing it until I found the right steps to move on to the next process. My voice was also very soft because I wanted to focus on completing it.*

The findings indicate that, at this stage, embodied cognition serves as a transition mechanism from understanding to strategic planning. Writing gestures indicate that the solution plan is not simply thought out mentally but is gradually constructed through symbolic activity on the answer sheet. Confused expressions, quiet voices, and head-palming gestures indicate cognitive load when the subject must select the most relevant concept. However, these behaviors are not simply signs of difficulty but rather part of a self-regulatory process aimed at stabilizing focus. The return of gaze to the image indicates that the previous visual representation serves as a primary basis for developing a formal plan. Thus, embodied cognition at this stage helps the subject connect the visual representation with the mathematical strategy to be used.

c. Stage of Implementing the Solution (T.3)

The following are the results of observations from the answer sheets and the subjects' embodied cognition during the solution of the geometry problem.

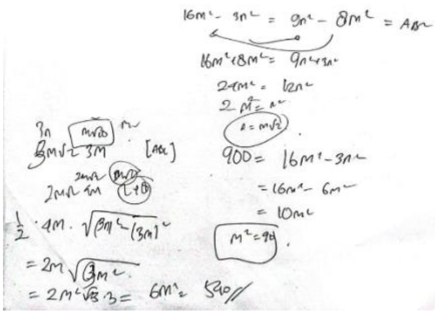


Figure 6. Subject Answer Sheet for T.3 Geometry Questions

Figure 7. Writing Gestures, Facial Expressions, Eye Gaze, and Body Posture of Subjects in T.3

Based on Figures 6 and 7, during the planning implementation phase, the dominant gesture was writing as the subject continued calculations, determining the values of the variables m and n, and substituting them into the triangle area formula. At the beginning of this phase, the subject appeared silent, with his eyes fixed on the questions and answer sheet. His facial expression showed hesitation, accompanied by small body movements such as supporting his head. As the writing process continued, utterances began to appear with varying tones, sometimes rising and sometimes falling. At the end, the subject's facial expression changed to a broad smile.

The following is an excerpt from an interview at the stage of implementing the plan.

S	:	*When you started doing the calculations, you looked focused on writing without talking, and your facial expression showed confusion while you propped your head up. What were you doing at that time?*
P	:	*I was concentrating on finishing the calculations, so I stayed quiet to avoid making mistakes. Then, I also had a moment of doubt about the steps, so I tried to rethink it while looking at the problem and my notes.*
S	:	*Then, as you progressed through the next stages of the work until the final stage, you started speaking with a rising and falling tone of voice, and at the end, you appeared to be smiling broadly. What was the meaning behind that?*
P	:	*The rising tone of voice occurs when I feel confident and emphasize important steps, while the slower pace reflects moments of uncertainty.*

These findings indicate that during the implementation phase, embodied cognition serves as a monitoring tool during strategy execution. The writing gesture is not merely a recording activity but also a medium for thinking, maintaining the sequence of steps and procedural consistency. Silence at the beginning of the process indicates high concentration, while changes in tone of voice reveal the dynamics of internal evaluation of the steps being carried out. Hesitant expressions and head-rest movements indicate a local check-in process, although not yet at the stage of thorough examination. A smile at the end indicates increased confidence after the subject sees that the calculation process leads to the result they believe is correct. Thus, embodied cognition at this stage plays a role in regulating focus, monitoring the accuracy of steps, and strengthening confidence in the interim results.

d. Looking Back Stage (T.4)

During the rechecking stage, no embodied cognition was apparent. The subject did not exhibit any additional movements or utter any words because, after finding the answer, the subject immediately moved on to the next question without rechecking.

The following is an interview excerpt at the re-examining stage.

S : *After you obtained the final result that was asked, did you recheck it?*
P : *No, I didn't.*
S : *Are you sure the steps you're taking are correct?*
P : *God willing, yes.*

Based on observations and interviews, it can be interpreted that there was no visible activation of embodied cognition at the rechecking stage. The absence of gestures, speech, or corrective actions indicates that the subject stopped at a feeling of certainty about the results without further verification. This finding is important because it shows that embodied cognition in problem-solving is not evenly distributed across all stages. In this case, the involvement of body and speech was strong at the understanding, planning, and implementation stages, but did not continue to the final reflection stage. This indicates that the subject's confidence in the answer was more dominant than the habit of rechecking procedures and results.

The form of embodied cognition manifested by the subject in the process of solving geometry problems is described in detail below.

a. Understanding the Problem Stage (T.1)

The following are the results of observations from the answer sheet and the subject's embodied cognition at the stage of understanding the problem in algebra questions.

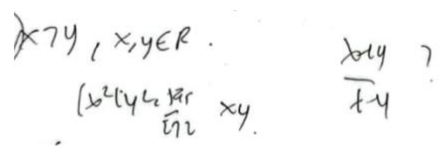


Figure 8. Subject Answer Sheet on T.1 Algebra Questions

Figure 9. Writing Gestures, Eye Gaze, and Body Posture of Subjects in T.1

Based on Figures 8 and 9, at this stage, the gestures that emerge are writing gestures as the subject records known and requested information in the algebra problem. Eyes move alternately between the problem and the answer sheet. Speech is slow and concise as the subject rereads the written information. Body posture appears calm, slightly leaned forward, with slow breathing.

The following is an interview excerpt at the stage of understanding the problem.

P : *In this algebra question, what do you write first to make it easier for you to solve the math problem?*

S : *It's still the same as before. The first thing I do is read and understand the question first. I write down all the information in the question on the answer sheet, from what is known to what is asked in the question.*

P : *While working on the questions, your body position looked calm and slightly leaning forward, and there was a slow breath. What did you feel at that moment?*

S : *Yes, I intentionally leaned forward to focus better. I usually breathe slowly to calm myself down and avoid rushing my thoughts.*

Data interpretation indicates that embodied cognition during the problem-understanding stage is simpler in algebra than in geometry. Representational gestures do not appear, and subjects rely more on writing gestures and body posture adjustments. This indicates that the nature of algebra problems encourages subjects to build understanding through symbolic organization rather than visualization of forms. Calm body posture, a forward-leaning position, and slow breathing indicate the regulative function of embodied cognition, which helps subjects maintain focus and manage their thinking tempo. Thus, at this stage, embodied cognition primarily stabilizes concentration and organizes symbolic information.

b. Solution Planning stage (T.2)

The following are the results of observations from the answer sheets and the subjects' embodied cognition during the planning stage of solving algebra problems.

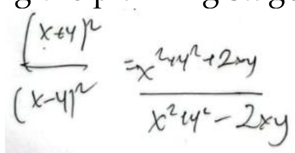


Figure 10. Subject Answer Sheet for T.2 Algebra Questions

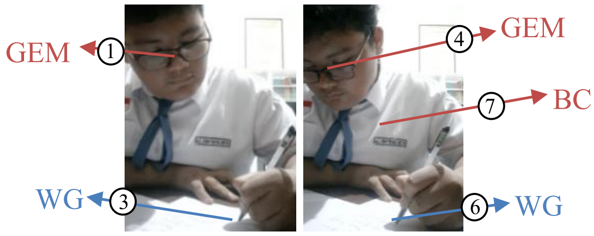


Figure 11. Writing Gesture, Eye Gaze, and Body Posture of Subjects in T.2

Figures 10 and 11 show that during the planning stage of the solution, the subject demonstrates writing gestures to organize the steps of the algebraic manipulation. Speech is low-voiced with a relatively steady tone. Body posture remains calm, tending to be silent, and gaze continuously shifts between the problem and the answer sheet throughout the planning process.

The following is an excerpt from an interview conducted at the solution planning stage.

P	:	*What did you do to make it easier to solve the problem?*
S	:	*Since the question asks for the value of* $\frac{x+y}{x-y}$, *I wrote down the next steps from my exponentiation to the power of 2, which becomes* $\frac{(x+y)^2}{(x-y)^2} = \frac{x^2+y^2+2xy}{x^2+y^2-2xy}$
P	:	*Earlier, you spoke softly and your body language was calm and often silent. What was the purpose of that?*
S	:	*Yes, my voice was soft to make sure that the steps I had planned were correct, and I kept my body calm so that I could focus better on my thinking.*
P	:	*Then why do your eyes keep shifting back and forth between the question and the answer sheet?*
S	:	*That's so that the plan I've made stays in line with the question, sir.*

The findings indicate that embodied cognition at this stage supports procedural planning. Writing gestures serve as a means of externalizing the algebraic manipulation steps, allowing the initially mental plan to become more structured and monitorable. Slow speech and a calm body indicate that the subject is internally testing the feasibility of the steps. Constantly shifting gaze indicates a matching process between the problem's demands and the plan being developed. In other words, embodied cognition here does not play a role in visualization, as in geometry, but rather in maintaining the accuracy of symbolic transformations and the continuity of the solution plan.

c. Stage of Implementing the Solution (T.3)

The following are the results of observations from the answer sheets and the subjects' embodied cognition during the implementation of the plan on algebra questions.

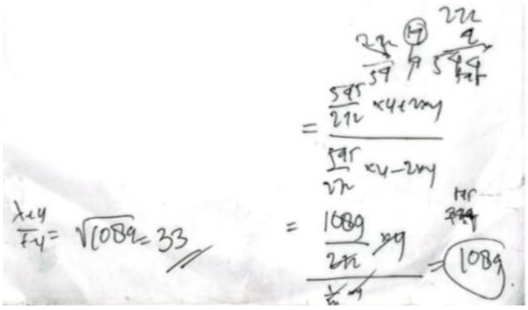


Figure 12. Subject Answer Sheet for T.3 Algebra Questions

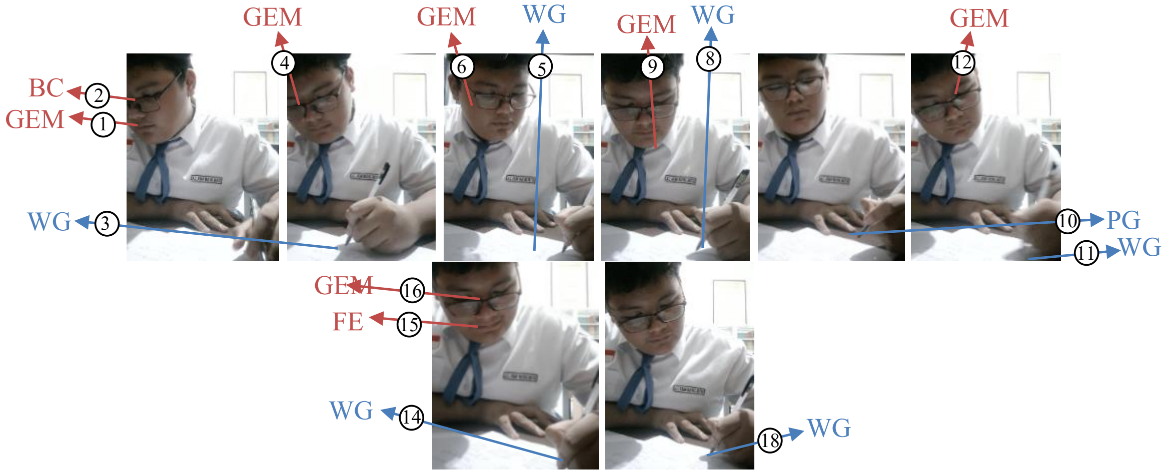


Figure 13. Writing Gestures, Facial Expressions, Gaze Direction, Body Posture, and Subject Pointing Gestures in T.3

Figures 12 and 13 show that during the solution plan, the subject exhibited several indicators of embodied cognition, namely a calm posture with a slight forward lean and slow breathing. Writing gestures consistently accompanied the calculation steps, including several facial expressions, such as a slight smile. The gaze was focused on the answer sheet, following the lines of writing. Speech was delivered in a slow, varied tone, sometimes rising to emphasize important steps and sometimes lowering to ensure the accuracy of the calculation. In addition, at the end, the subject showed a pointing gesture before writing the final result.

The following is an excerpt from an interview at the stage of implementing the plan.

P : *During the calculation, you kept writing and smiled slightly several times. What does that indicate?*

S : *The smile appeared because I began to feel confident that the steps were correct and the calculations were leading to the result.*

P : *While working on the calculations, why did your body appear calm and slightly leaning forward, accompanied by slow breathing and a voice that sometimes sounded high-pitched and sometimes low-pitched?*

S : *So I can focus better, I regulate my breathing to stay calm and maintain concentration. The higher pitch is to emphasize important steps, while*

		the slower or lower pitch usually happens when I double-check my calculations.
P	:	*Then, at the end, you pointed to the answer sheet. Why did you do that?*
S	:	*Yes, I pointed to the answer sheet because I knew that $x > y$, so I wrote the final result with a positive value.*

These findings suggest that during the planning and implementation phase, embodied cognition serves as a tool for controlling procedural accuracy and justifying results. Consistent writing gestures indicate that the thought process is proceeding alongside symbolic execution. Variations in tone of voice signal an internal evaluation of the steps being taken, while breath control and body posture help maintain stable concentration. A slight smile indicates increasing confidence in the direction of the solution. Most importantly, the gesture of pointing at the end indicates that the subject not only completed the procedure but also linked the results to the problem's initial conditions. This suggests that, at this stage, embodied cognition helps the subject connect the calculation process to the validity of the written answer.

d. Looking Back Stage (T.4)

In the review stage, there was no apparent embodied cognition. The subject made no gestures or utterances. This occurred because, after completing the entire problem and without reviewing it, the subject immediately informed the researcher that the problem had been solved and handed in the work.

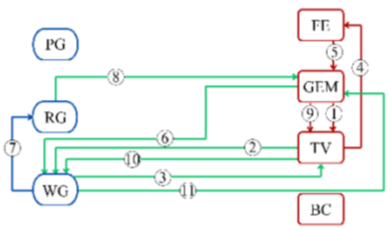
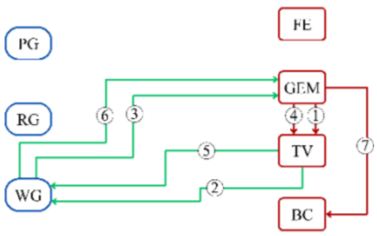
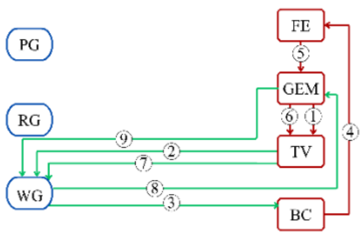
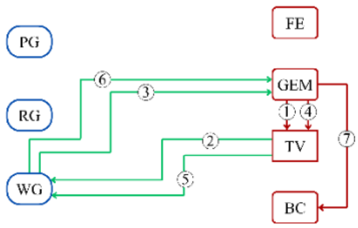
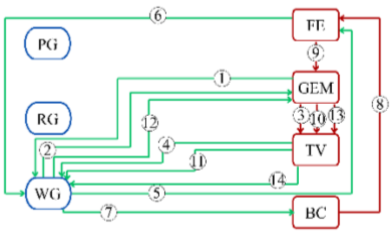
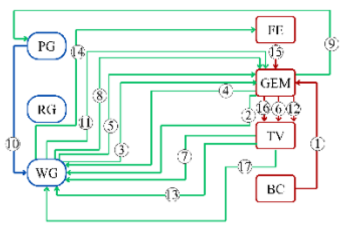
The following is an excerpt from the researcher's interview with the subject during the review stage.

S	:	*Have you double-checked the answers you obtained?*
P	:	*No.*
S	:	*Are you sure the steps you're taking are correct?*
P	:	*Yes, I am.*

Based on observations and interviews, it can be inferred that embodied cognition was not activated during the rechecking stage. The absence of corrective actions, gestures, or utterances indicates that the subjects ended their problem-solving when they felt their answers were sufficiently convincing. This finding reinforces a pattern that also emerged in geometry problems: the final reflection stage had not yet become a prominent part of the subjects' strategies. Thus, the absence of embodied cognition at this stage indicates that the verification process was not explicitly carried out, either cognitively or through bodily manifestations

Discussions

Table 2. Observation Results of Embodied Cognition Comparison in the Problem-Solving Stage

TPM	Geometri		VS	Aljabar	Information
	Embodied Cognition				
	Gesture	Utterance	Gestur	Utterance	
T.1					In geometry problems, gestures are manifested in the form of pointing gestures and representational gestures, while utterances are manifested through gaze and eye movement, tone of voice, and facial expressions. Meanwhile, in algebra problems, gestures are manifested only in the form of writing gestures, while utterances are manifested through gaze and eye movement, tone of voice, and body posture.
T.2					In geometry problems, the gestures manifested are only pointing gestures, while utterances are manifested through gaze and eye movement, tone of voice, facial expressions, and body posture. Meanwhile, in algebra problems, the gestures manifested are only writing gestures, while utterances take the form of gaze and eye movement, tone of voice, and body posture.
T.3					In geometry questions, the gestures used are only pointing gestures, while utterances are expressed through gaze and eye movement, tone of voice,

TPM	Geometri	VS		Aljabar	Information
	Embodied Cognition				
	Gesture	Utterance	Gestur	Utterance	
					facial expressions, and body posture. Meanwhile, in algebra questions, the gestures used are writing and pointing gestures, while utterances are expressed through body posture, gaze and eye movement, tone of voice, and facial expressions.
T.4	PG RG WG	FE GEM TV BC	PG RG WG	FE GEM TV BC	In geometry and algebra problems, gestures and utterances are not manifested by the subject.

This study demonstrates that embodied cognition in OSNK winning subjects consistently appears at the stages of understanding the problem, planning a solution, and implementing the plan, but is absent at the reexamination stage. This finding confirms that gestures and utterances are not merely behaviors that accompany thinking activities, but rather part of the mathematical thinking mechanism itself. In this context, the body helps construct problem representations, develop strategies, and monitor the accuracy of solution steps. This finding aligns with embodied cognition theory, which holds that mathematical thinking is closely related to physical activities, such as hand movements, gaze direction, facial expressions, and changes in intonation (Abrahamson et al., 2020).

At the problem-understanding stage, embodied cognition appeared richer in geometry problems than in algebra. In both materials, subjects used writing gestures, alternating gaze between the problem and the answer sheet, and changes in tone of voice to highlight important information. However, in geometry, representational gestures appeared to visualize shapes and spatial relationships, while in algebra, bodily composure and breath control were more apparent. This difference occurs because geometry demands visualization of objects and spatial relationships, allowing the body to help construct more concrete mental representations. Conversely, algebra demands more symbolic precision and formal manipulation, so the dominant embodied cognition supports focus and stability of thought. This finding aligns with the view that gestures not only reflect thoughts but also help construct mathematical meanings that are difficult to convey verbally (Seccia & Goldin-Meadow, 2024b). This pattern is consistent with previous research, which showed that geometry tasks tend to elicit representational gestures, while algebra tasks elicit more writing gestures because they are more closely related to symbolic and procedural manipulation (Schindler et al., 2025) (Kokushkin & Tech, 2020). Thus, the scientific findings that can be drawn are not simply that there are differences in gestures, but that the cognitive structure demanded by the material determines the form of bodily involvement in mathematical thinking (Sriramulu et al., 2019). In the context of OSN winning students, this also shows high adaptability; the subject can adjust the form of his body involvement to meet the needs of problem-solving (Yudianto et al., 2025).

In the planning stage of solving, writing gestures, a low voice, and eye contact remain the dominant forms of embodied cognition. However, in geometry, confused expressions and tense body postures, such as head-holding, appear, which are less pronounced in algebra. This suggests that planning in geometry requires a more complex restructuring of representations, as subjects must connect images, shape properties, and relevant concepts before selecting a strategy. In contrast, in algebra, planning appears calmer because subjects tend to have more readily available procedural schemes. Thus, the confusion that emerges in geometry cannot be understood simply as difficulty, but as a sign of deeper cognitive work. These findings support the view that mental processes and gestures are interdependent in managing attention and cognitive load (Deligiannis, 2018), and align with the nature of geometry, which demands more visualization than algebra, which is more symbolic and logical (Battista et al., 2018). In this context, the subject as an OSN student demonstrates the ability to adapt thinking strategies and self-regulation according to the demands of the material (Gunardi & Djuwita, 2024)

At the planning implementation stage, writing gestures were the most consistent form of embodied cognition across both materials. This suggests that writing serves not only to record results but also as a means of thinking that helps subjects maintain sequences of steps, organize logic, and reduce working memory load. In geometry, changes in facial expression and variations in tone of voice indicate the dynamics of internal evaluation, from doubt to confidence. In algebra, in addition to writing gestures, pointing gestures are used to link the final result to the problem's conditions. This suggests that gestures serve not only a representational function but also a justificatory and metacognitive function, as they help subjects monitor and confirm the correctness of the steps taken. These findings align with the view that utterances can signal doubt, affirmation, and confirmation in mathematical thinking(Dwijayanti, Budayasa, and Siswono 2019). This pattern reflects the characteristics of OSN-winning students, who can adjust their thinking strategies and body language in response to the demands of the material when solving high-level mathematical problems (Zhang et al., 2022). At the problem-solving stage, the characteristics of embodied cognition are influenced by the nature of the material. Geometry, which is visual-spatial in nature, tends to elicit writing gestures and stable visual focus to maintain step accuracy, whereas algebra, which is symbolic-procedural in nature, shows greater variation in utterances and pointing gestures to emphasize symbol relationships and calculation results (Pier et al., 2019). This pattern reflects the characteristics of OSN student who have strong conceptual mastery and high metacognitive awareness. Student can efficiently adjust their use of gestures and utterances to meet the demands of the material, thereby making the problem-solving process more focused, systematic, and confident (Wells, 2017).

At the rechecking stage, gestures and utterances were absent. Directly, this occurred because the subjects felt confident in the answers they obtained. However, more critically, this finding suggests that high confidence is not always followed by explicit verification. This means that the absence of embodied cognition at this stage not only indicates certainty but may also indicate that the habit of final reflection has not yet become a strong part of the subjects' problem-solving strategies. This finding aligns with (Widiati dan Wutsqa, 2017) This indicates that many students do not double-check because they feel their answers are correct. In the context of National Science Olympiad (OSN) students, this can be understood as a result of conceptual mastery and experience solving high-level problems, but it also poses a metacognitive weakness, as the review stage within Polya's framework is crucial for ensuring the validity of the solution. In other words, the subject's thinking efficiency can be a strength, but it can also compromise accuracy in the final stage.

The implications of these findings for mathematics learning are quite broad. Teachers need to view students' gestures, eye contact, intonation, facial expressions, and body language as indicators of thought processes, not merely additional behaviors. In geometry lessons, teachers can provide space for students to use hand gestures, point to shapes, redraw, or visually represent spatial relationships so that understanding doesn't stop at memorizing formulas. In algebra lessons, teachers can get students used to writing steps sequentially while explaining the rationale for the symbolic transformations they perform. This strategy is important because research shows that writing gestures and utterances can help maintain accuracy and clarify the relationships between steps. Thus, mathematics learning should accommodate multimodal representations, rather than solely emphasizing the final symbolic answer. Another equally important implication is the need to cultivate the habit of double-checking. Because even highly capable students tend not to engage in explicit verification, teachers and trainers need to design activities that consciously cultivate reflective habits. For example, students could be asked to mark the most likely incorrect steps, re-explain the reasons for their answers, match the final result to the problem's requirements, or use a simple checklist before declaring a problem solved. This approach will help develop students' metacognitive awareness, so that mathematics learning produces not only fast and accurate students but also thorough and reflective ones. In the context of OSN coaching, this is especially relevant because small errors often arise not from weak concepts, but from the lack of an adequate final verification stage.

Thus, this discussion shows that the research findings do not stop at identifying the types of gestures and utterances that emerge, but lead to a deeper understanding of why these forms emerge, how they relate to the theory of embodied cognition, and what impact they have on the practice of mathematics learning. Embodied cognition in mathematical problem-solving among OSN-winning students arises because the body helps meet the demands of representation, attention regulation, and justification of different results in geometry and algebra. Therefore, effectivTherefore, effective mathematics learning should not separate the cognitive from the bodily aspects, but rather integrate them so that students can build a stronger understanding, develop strategies, and reflect on their problem-solving.

Conclusions and Suggestions

This study demonstrates that embodied cognition in OSNK winning students is an important part of the mathematical thinking process. Gesture and utterance do not appear separately; they interact to support problem understanding, strategic planning, and solution implementation. In geometry problems, embodied cognition appears more diverse through representational gestures, writing gestures, facial expressions, and variations in tone of voice, helping visualize shapes and spatial relationships. On the contras, in solving algebra problems, embodied cognition is more strongly embodied in writing gestures, pointing gestures, eye gaze, and body composure to maintain focus and accuracy in symbolic manipulation. These findings confirm that embodied cognition is adaptive and context-dependent, as it adapts to the material's characteristics and the cognitive demands of the problem.

The contribution of this research lies in explaining the integrated relationship between gesture and utterance in presenting the mathematical thinking process of high-ability students, especially high school OSNK winners. In practice, this study's results indicate that teachers and Olympiad coaches should pay attention to students' gestures, gaze direction, intonation, and facial expressions as indicators of the thinking process, rather than just assessing the final answer. Mathematics learning also needs to provide space for the use of multimodal representations so that students' thinking processes are more focused and meaningful. Future research is recommended to involve more subjects with varying ability levels and a wider range of mathematical materials to obtain a broader picture of embodied cognition.

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