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Understanding mathematical concepts in students with borderline intellectual functioning: Insights from representational gestures

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Abstract

When solving problems, the spontaneous actions of students identified as slow learners (SL) often reflect their cognitive limitations. This study analyzed students' SL understanding of mathematical concepts through representational gestures as a means of communication in constructing concepts. A qualitative case study was conducted in a public junior high school in Lamongan Regency. From eight SL students identified through IQ tests and teacher interviews, only three consistently used representational gestures and were selected as the subjects. Although limited, this sample enabled an in-depth analysis while acknowledging restricted generalization. Data were collected through functional tasks, gesture observations, and interviews and were then analyzed interactively through data reduction, display, and conclusion drawing. The results showed that SL students frequently used hand gestures to represent graph axes or intersection points but misinterpreted variable relationships. They could only classify objects based on conceptual conditions, while other indicators of understanding were not attained. These findings suggest that teachers should consider students' gestures not only as spontaneous expressions but also as diagnostic cues for misconceptions and as a support for mathematical communication.

Keywords: representational gesture; slow learner; understanding of mathematical concepts

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Introduction

Understanding mathematical concepts is fundamental to learning mathematics. Conceptual understanding greatly affects students' ability to solve various mathematical problems effectively and meaningfully. A good conceptual understanding allows students to solve diverse problem types and improve their performance (Zhang et al., 2024). Root (2019) stated that mathematics learning cannot run smoothly if students do not understand mathematical concepts. Therefore, understanding and mastery of mathematical concepts are crucial in mathematics learning, serving to expand and strengthen students 'existing mathematical knowledge (Susanto, 2014).

A poor understanding of mathematical concepts is not only a local problem but also a global one. International assessment results consistently demonstrate this fact. For example, in the 2012 Program for International Student Assessment (PISA), only approximately 55% of 15-year-old students worldwide were able to answer simple questions about interpreting tables (OECD, 2014). Similarly, the 2023 Trends in International Mathematics and Science Study (TIMSS) showed that despite improved performance, approximately 9% of fourth-grade students in Australia still lag behind and lack basic arithmetic (Mullis et al., 2023). These findings confirm that poor conceptual understanding remains a major challenge in mathematics education, emphasizing the need for instructional strategies that prioritize conceptual development over procedural fluency. This lack of understanding of mathematical concepts shows how mathematics should be taught and applied to develop students' understanding of concepts and procedures in educational research (Yimam & Dagnew Kelkay, 2022).

Developing students' conceptual understanding of mathematics has long been a central concern for educators. Various learning strategies have been developed for this purpose, such as game-based learning, which has been shown to enhance motivation and support students' understanding (Chen et al., 2025). Providing concrete examples has also been identified as an effective way to strengthen conceptual understanding (Gashaj et al., 2023). However, not all students possess the same cognitive capacity to construct mathematical concepts, particularly students identified as Slow Learners (SL), also referred to as individuals with Borderline Intellectual Functioning (BIF). In this study, the term "slow learner" refers to students with IQ scores typically ranging from 76 to 89, corresponding to the borderline intellectual functioning category as described in the DSM-5 (APA, 2013). Although the term "slow learner" is still commonly used in the Indonesian educational context, this study aligns it with the international construct of BIF to ensure conceptual clarity. Students identified as slow learners generally exhibit distinctive cognitive characteristics that influence their understanding of mathematics. They are often able to perform routine tasks but face challenges in non-routine or abstract problem situations, indicating that their procedural fluency is often stronger than their conceptual understanding (Azzahra & Herman, 2022). Consequently, these students require structured, contextualized, and multisensory pedagogical approaches to foster a deeper conceptual understanding (Borah, 2013).

Efforts to design learning approaches for students with learning difficulties, including those identified as slow learners (SL), have become crucial in education to enhance both academic understanding and learning motivation. Previous studies have proposed various models, such as constructivist models, Polya's problem-solving framework, and scaffolding, to integrate culturally relevant technology-based media, all emphasizing adaptive and inclusive learning (Wanabuliandari et al., 2025). Learning designs based on mnemonic strategies have also been shown to be effective in improving vocabulary retention in students (Ridha & Nurdibyanandaru, 2018), while the RME approach is used to adapt mathematical concepts to students' real-life experiences (Listiawati et al., 2023). Moreover, movement-based e-learning innovations, such as Kinect, have enabled students with disabilities to become more interactive during the learning process (Faisal et al., 2016). These efforts seek to address typical learning challenges, such as difficulty recalling concepts, reasoning, developing problem-solving strategies, and understanding mathematical processes (Wafiqoh et al., 2022). Despite these developments, most existing studies have focused on the development of learning models, strategies, or media. Very few studies have explored how students identified as slow learners construct conceptual understanding through nonverbal communication, particularly gesture representation. However, gestures function not only as spontaneous expressions but also as reflections of students' cognitive processes in constructing and communicating mathematical ideas.

Students with limited verbal communication skills often find it difficult to express their mathematical reasoning verbally or in writing due to linguistic and expressive limitations (APA, 2013; Heward, 2013). However, research has shown that when verbal communication is limited, these students attempt to express their thoughts through other modalities, one of which is gesture. Sovia and Herman (2020) found that in the process of solving mathematical problems, students with special needs produce gestures that function as cognitive tools for understanding and refining their thought processes. This aligns with the theory of embodied cognition, which has been widely discussed in mathematics education in the past two decades. According to Pier et al. (2019), cognitive abilities are closely connected to bodily actions and the perceptual systems. Thus, gestures are not merely communicative tools but also cognitive representations that help students visualize and organize mathematical concepts concretely. Within this framework, gestures serve as a bridge between action and thought (Francaviglia & Servidio, 2011). When solving problems, students process and understand ideas through their bodies and senses; therefore, the body plays a central role in shaping cognition (Wilson, 2002).

Building on these perspectives, this study adopts an explicit theoretical framework that integrates embodied cognition (Wilson, 2002), gesture typology (McNeill, 1992), and contemporary work on gestures as cognitive tools (Alibali & Nathan, 2012; Goldin-Meadow, 2003; Hostetter & Alibali, 2008). Specifically, we distinguish three functional roles of gestures in reasoning: (a) co-speech gestures that accompany and reinforce spoken explanations; (b) thinking-for-speaking gestures that scaffold verbalization and organize thought prior to speech; and (c) standalone cognitive gestures that operate as externalized mental simulations even in the absence of speech (Goldin-Meadow, 2003; Hostetter &

Alibali, 2008). This distinction is important for interpreting whether a gesture primarily supports communication, supports the online formulation of ideas, or functions as an independent problem-solving tool.

Gestures are implicit, spontaneous, and non-verbal forms of expression that occur within the context of embodied cognition. Through a multimodal perspective, gesture can be interpreted as a representational form that connects bodily movement with cognitive processes, contributing to focus and interaction during mathematics learning (Alibali & Nathan, 2012; Dirusso, 1999; Francaviglia & Servidio, 2011; Radford et al., 2009). For students who struggle to convey ideas verbally, gestures serve as a means of externalizing and refining their mathematical thinking. Furthermore, gestures assist in the development of conceptual understanding, particularly in situations requiring problem solving, information processing, or working memory engagement (Hord et al., 2016; Walsh & Hord, 2019). Hence, gestures are not just physical movements but essential cognitive tools for constructing and organizing mathematical understanding.

To make our analytic lens explicit, we map gesture types to Skemp (1978) indicators of conceptual understanding: (1) iconic gestures (which depict concrete attributes or actions) are expected to relate to Skemp's indicator of classifying objects and connecting concepts; (2) metaphorical gestures (which render abstract relations through embodied schemas) are expected to relate to Skemp's indicators of formulating necessary/sufficient conditions and applying concepts in novel contexts. This operational mapping guided our coding and interpretation of gesture cognition relationships in the present study.

For students identified as slow learners, gestures can act as a cognitive bridge that transforms abstract mathematical concepts into concrete and intuitive representations. Due to their difficulty in processing abstract ideas (Shaw, 2010), these students often exhibit nonverbal forms of communication when verbal expression is challenging. Sovia and Herman (2020) revealed that students identified as slow learners produce representational gesture patterns when solving mathematical problems. These gestures appear when students are unable to verbalize their reasoning but still attempt to express their understanding through movement. Similar findings by Elvierayani et al. (2023) and Elvierayani et al. (2025) confirm that representational gestures play a central role in the mathematical problem-solving processes of students identified as slow learners.

Based on this gap, this study aims to examine the understanding of mathematical concepts among students identified as slow learners (SL) through the representational gestures they use when solving mathematical problems. This approach is expected to broaden the theoretical understanding of the relationship between gestures and cognitive processes in students with learning difficulties while contributing to the development of inclusive mathematics education that integrates the verbal, nonverbal, and cognitive dimensions of conceptual learning.

Methods

This study employed a qualitative case study design (Creswell & Creswell, 2018) to explore the understanding of mathematical concepts among students identified as slow learners (hereafter referred to as students with borderline intellectual functioning) based on the gesture representations they produced during problem-solving. A case study approach was selected to gain an in-depth understanding of a specific educational context involving students with unique cognitive profiles. The research was conducted at a public junior high school in Lamongan Regency, East Java, Indonesia. Subjects were selected through a multi-stage process involving both teacher identification and cognitive assessment. Initially, the mathematics teachers nominated eight students who showed persistent difficulty in abstract reasoning and slower learning progress. This preliminary identification was supported by the learning records and interviews.

The nominated students then took a standardized IQ test administered by a psychologist. The IQ results (range 76–89) were used as supportive cognitive indicators, not as diagnostic labels, consistent with the operational definition of borderline intellectual functioning (BIF) (APA, 2013; Chauhan, 2011). From this group, three students were selected as focal participants based on the following criteria: (a) IQ range between 76 and 89, (b) consistent use of representational gestures during pre-observation, and (c) willingness to participate (we use the form of willingness to be a subject).

Using three participants allowed for a deep analysis of each student's gesture–concept relationship while minimizing the cognitive fatigue. Selection decisions were documented in a participant log (including teacher notes, assessment reports, and pre-observation summaries) to provide an audit trail of transparency. Task Design and Rationale Two function tasks were designed to elicit gestures that reflect different types of conceptual representation: Task 1: Function in an arrow diagram. This task required students to map the input and output values using arrows. This visual-spatial structure encourages iconic gestures that represent concrete mappings or directional relationships. Task 2: Functioning in a Cartesian coordinate system. The students were asked to plot discrete points and interpret their relationships. This setting tends to elicit metaphorical gestures used to represent abstract relationships (McNeill, 1992). Functions were selected because they require mapping and relational reasoning, two cognitive processes that are both conceptually abstract and visually representable, thus ideal for observing representational gestures and distinguishing between iconic and metaphorical gesture use (Alibali & Nathan, 2007; Goldin-Meadow, 2015).

Data were collected from three sources: (1) gesture observation, (2) written task responses, and (3) semi-structured interviews. All sessions were audio-visual recorded using two cameras to capture both facial expressions and hand movements. Interview prompts were designed to probe conceptual reasoning using lead questions that connected students' verbal and gestural responses. Each interview and observation lasted approximately 30–45 min.

Data analysis involved multiple steps to ensure rigor and transparency: (1) Transcription and segmentation. All the video data were transcribed verbatim. Gesture episodes were time-stamped and segmented based on movement boundaries following Alibali and Nathan (2007) gesture phase framework (iconic or metaphorical). (2) Coding protocol. Each gesture was coded as either iconic or metaphorical (Alibali & Nathan, 2007). Coding was guided by Skemp (1978) indicators of conceptual understanding: (a) classifying objects based on concept-forming requirements, (b) connecting concepts to one another, (c) developing necessary and sufficient conditions for a concept, and (d) applying concepts algorithmically in problem-solving. (3) Triangulation and discrepancy resolution: Triangulation was conducted across three data sources: gesture observation, written responses, and interviews. Discrepancies (e.g., when a gesture implied understanding but the written response did not) were discussed collaboratively among the researchers. The final interpretation was reached through peer debriefing sessions until a consensus was achieved. (4) Reliability and credibility of the data. Two researchers independently coded 30% of the data set. Disagreements were resolved through discussions. Subjectivity was minimized by using audit trails. (5) Data synthesis. Codes were clustered into broader categories and interpreted following Miles et al. (2014) interactive framework data reduction, data display, and conclusion drawing to develop a holistic understanding of how gestures reveal conceptual processes.

Results

Initial research stage

The main activity of this research was problem solving by the eight students identified as SL. The results showed that the eight students identified as SL produced several variations of gestures based on the classification (Alibali & Nathan, 2012) when solving problems. The results of student gesture variations were analyzed through data triangulation, comparing the results of initial observations, interviews, and assignment sheets to ensure data validity. The results of the variations in student gestures while solving problems are explained in Table 1.

Tabel 1. Gesture variations in potential subjects

No.	Subjects	Gesture Classification
1	S1	Pointing (deictic), representational, and writing
2	S2	Pointing (deictic), writing
3	S3	Pointing (deictic), representational, and writing
4	S4	Pointing (deictic) and writing
5	S5	Pointing (deictic) and writing
6	S6	Pointing (deictic) and writing
7	S7	Pointing (deictic) and writing
8	S8	Pointing (deictic), representational, and writing

Based on Table 1, the research subjects used in this study were S1, S3, and S8, respectively. The selection of these three subjects was based on the use of representational gestures by students identified as SL in solving function problems. The three subjects had previously undergone IQ tests to strengthen the class teacher's recommendation regarding the suspected SL condition experienced by the students according to Chauhan (2011) with IQ scores in the range of 76-89. The results of the students' IQ tests are presented in Table 2.

Table 2. Subject IQ test results

No	Subjects	IQ Score	Classification
1	S1	76	Borderline / SL
2	S3	78	Borderline / SL
3	S8	79	Borderline / SL

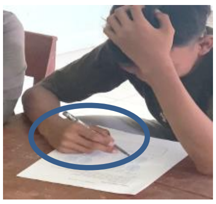
Based on Table 2, S1, S3, and S8 are SL students with IQ between 76-89. This is in accordance with the opinion of (Amir, 2013) that a student is said to be a student identified as having SL if he has an IQ between 70-90. The IQ scores also indicated that the three students had an intellectual capacity below most children with the same educational background and age. However, these students can learn new knowledge or skills that are concrete and practical but require more time than most children of the same age level. The results of the IQ test are one of the foundations that the selected subjects are appropriate to the research topic, namely, SL students. The selection of these three subjects also considered the depth of representational gesture analysis, and this number also allowed for a comprehensive analysis of gesture patterns without losing detail for each subject.

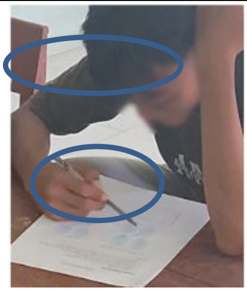
Understanding mathematical concepts in the first question

Subject 1

S1 is a student identified as an SL with an IQ score of 76. S1 was able to communicate and socialize quite well with his friends at school. During an interview with the researcher, S1 answered the questions clearly; however, S1 was not confident enough in his performance. When solving problems, S1 began by reading the questions in order, starting from number one to number three. S1 was able to understand the problem he faced. S1 also flipped through the problem assignment sheet from the first to the third question and then returned to the first. When asked about question 1 during the interview, S1 stated that the correct answers were 1(d) and 1(a). This was recorded in the following confirmation dialogue of S1's answer.

Table 3. S1 gesture protocol when clarifying answers to the first question

Speaker	Conversation	Gesture	Gesture Description
P	do you know what is function?		
S1	know, this, what, not cheating		While pointing to one of the images 1(c) and making a motion path between the two shapes in image 1(d)
P	What's not cheating?		

Speaker	Conversation	Gesture	Gesture Description
S1	Because there's nothing like this, ma'am		S1 uses representational movement on graph 1 (c) by drawing a line from arrow diagram 1 (X diagram) to another arrow diagram (Y diagram) in the air above the paper several times)

Based on the results of the interview with S1 for the first question, S1 was able to classify objects based on the requirements for forming the concept of function by grouping the types of diagrams presented in the question with the nature of the concept of function. It was seen that S1 was able to remember that diagrams 1(a) and 1(d) were functions on the grounds that the diagrams were “not cheating.” The phrase “not cheating” provided S1 with a deep conceptual understanding of the function concept. The results of the answers written by S1 regarding the reasons for choosing the graph were also written with the sentence “because it is not cheating.” This is illustrated in Figure 1.

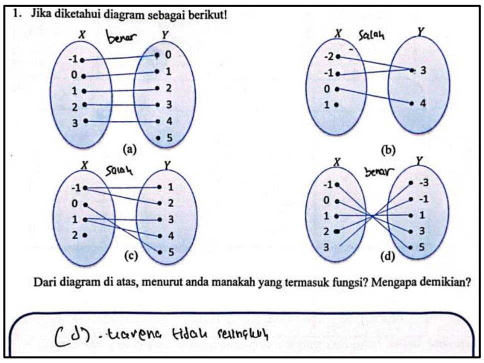


Figure 1. S1 answer results

Based on Figure 1, S1 associated the concept of function in the arrow diagram with the representation of lines that have only one pair, using the phrase “not cheating” to express this idea. However, rather than indicating full conceptual mastery, this phrase and the accompanying gesture (“not cheating” while pointing and tracing a path between the domain and codomain) were interpreted as an early attempt at meaning-making. Gestures like these reflect the student’s effort to connect verbal reasoning with visual relationships but may also signal partial or developing understanding (Cook & Goldin-Meadow, 2006; Goldin-Meadow, 2003). According to Skemp (1978) framework, this behavior corresponds to the initial level of conceptual understanding that classifies and connects objects based on perceived relationships but without articulating the formal definition of a function. Thus, S1’s gesture was categorized as a productive iconic gesture that helped externalize reasoning but did not yet demonstrate complete comprehension.

Subject 2

S3 was a student identified as an SL with an IQ score of 78. S3 is a quiet student but is able to communicate when prompted. During the interview for clarification of question 1, S3 answered that the correct diagrams were 1(a) and 1(d), explaining that the diagrams "were all in pairs." S3 performed a representational gesture by tracing a line from the domain to the codomain to illustrate this idea (Figure 2).

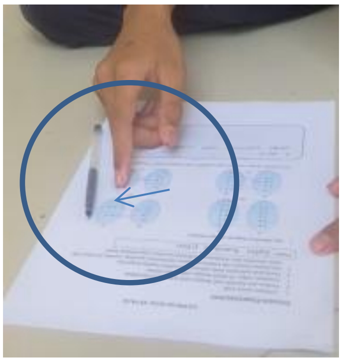


Figure 2. Representational gestures by S3

S3 demonstrated reasoning by identifying which diagram met the criteria of a function and which did not, referring to those that were "cheating" as nonfunctions. indicates that S3 could classify objects based on perceived concept-forming requirements and relate one concept to another, although not yet able to precisely verbalize the mathematical definition of a function. The representational gesture observed in S3 was categorized as iconic because it visually depicted the relationship between the domain and codomain in a concrete manner.

However, the interpretation of this gesture does not imply a full conceptual understanding. Instead, following Cook and Goldin-Meadow (2006) and Goldin-Meadow (2003), such gestures are considered evidence of cognitive engagement and an attempt at meaning-making through embodied representation. In this case, S3's gesture was identified as a productive iconic gesture because it helped externalize relational reasoning, even though the verbal explanation remained incomplete. According to Skemp (1978) indicators, this corresponds to the stage of "classifying objects and connecting concepts," reflecting an emerging but not yet consolidated understanding of the function concept. The combination of limited verbal articulation and productive gesturing suggests that S3's cognition was actively supported by embodied representation rather than by abstract formal reasoning.

Subject 3

S8 was a student identified as having SL with an IQ score of 79. He is known among his peers to be a sociable child. During classroom activities, S8 often appeared unfocused and tended to make jokes with friends. In the interview confirming his answer to question 1, S8 stated that diagram 1(d) represents a function, as shown in Figure 3.

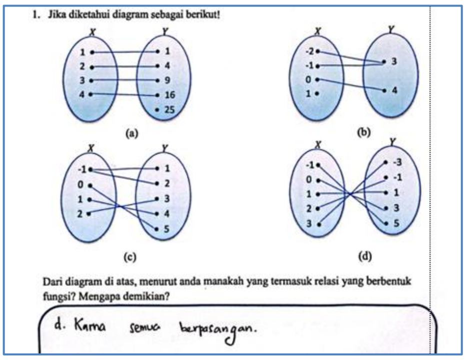


Figure 3. S8 answer results

At minute 00:04-00:10 S8 pointed to graph 1(d) using a pencil, and during the interview, S8 explained that " I am looking for a pair, ma'am". This indicates the emergence of a representational gesture made by S8 regarding his understanding of the function problem indicated by the word "pair." The following interview was recorded:

P : "Looking for pairs, what do you mean?"
S8 : "These are the pairs -1 and 5, then 0 and 3, then the pairs"
P : "Ooh…what about the others that aren't pairs? Maybe A?"
S8 : "Yes, ma'am, there's one that isn't a pair, ma'am"

Based on Figure 3 and the results of the interview with S8, it is known that S8 can classify objects based on his understanding of the concept of function, which requires a pairing between the domain and its codomain. S8 produced representational gestures that demonstrated the development of the necessary conditions for the concept of a function. However, further analysis revealed that S8's gestures were not entirely consistent with the mathematical representation of functions. At certain moments, S8 produced a "square" motion with his hand that did not align with the domain–codomain structure. Following Cook and Goldin-Meadow (2006) and Goldin-Meadow (2003), this gesture was interpreted as a non-productive metaphorical gesture that reflected cognitive struggle or uncertainty rather than stable understanding. Such gestures often emerge when learners attempt to reason with incomplete or conflicting ideas under cognitive load.

Although S8 partially understood that a function involves a unique pairing between the domain and codomain, his explanation and gesture showed that this knowledge had not yet been internalized conceptually. According to Skemp (1978) framework, this indicates that S8 was at the stage of developing the necessary and sufficient conditions of the concept but had not yet reached algorithmic application. Therefore, S8's gesture served as a non-verbal cue of emerging but unstable reasoning, an attempt at meaning-making rather than evidence of conceptual mastery.

Understanding mathematical concepts in question two

Subject 1

When solving the second question related to functions and non-functions represented in a Cartesian diagram, S1 appeared to take longer than in the first question. At 02:03, S1 began a representational movement from the origin (O) upward, then to the right (positive direction), and back downward. Initially, these movements did not leave a mark on the paper until they were repeated several times with a writing gesture, eventually producing a visible trace. Subsequently, S1 continued to perform similar movements (repeated several times) without leaving a scribble. At minute 02:08, S1 wrote on question 2(i) on the top problem assignment sheet, as shown in Figure 4.

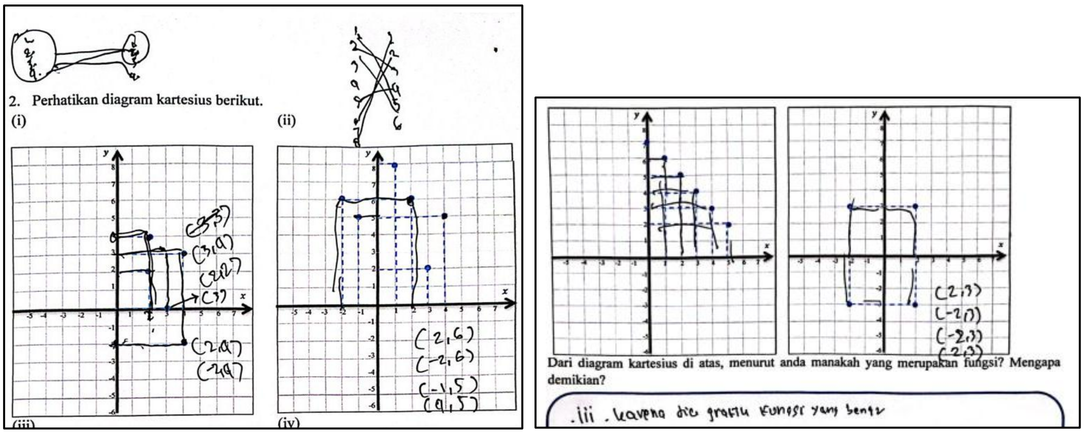


Figure 4. S1's answer results in the second question

Based on Figure 4, S1 S1 attempted to reinterpret the Cartesian representation through physical movements similar to those in the previous task. During the process, S1 demonstrated a representational gesture that reflected an effort to connect spatial relationships linking coordinate points to functional mappings. However, while these gestures showed cognitive engagement, they did not yet indicate mastery of the concept. Following (Cook & Goldin-Meadow, 2006), such gestures are better viewed as transitional indicators of meaning-making rather than as proof of understanding. Further analysis revealed that S1's gestures alternated between productive iconic gestures when visually tracing relationships between domain and range and non-productive metaphorical gestures when movements became inconsistent with coordinate positions. The confusion between (2,4) and (4,2) indicated cognitive instability rather than a lack of effort, showing how gestures can externalize both reasoning and uncertainty simultaneously.

Although S1's final answer identifying graph 2(iii) as a function was correct, the reasoning did not fully meet Skemp (1978) indicator of conceptual understanding. S1 was able to connect one concept to another but had not yet formulated the necessary and sufficient conditions for defining a function within the Cartesian framework. The gestures, therefore, served as non-verbal representations of emerging conceptual reasoning, providing insight into S1's embodied thinking process under cognitive load.

Subject 2

When solving the second problem, S3 selected answers (i) and (iv). At minute 01:39, S3 produced a pointing gesture followed by a representational gesture (metaphoric) while giving reasons on the task sheet regarding the graphs chosen as functions. The results of S3's work on the second question are presented in Figure 5.

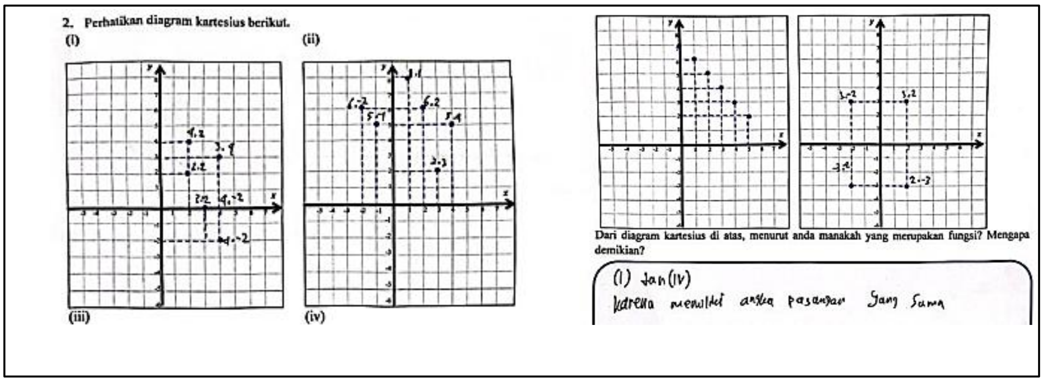


Figure 5. S3's answer results for the second question

The written and verbal explanations indicated that S3's reasoning could not yet describe the concept of a function mathematically. During the interview, S3 explained that in graph (i), "the numbers are all the same," referring to how the coordinate points were positioned. While explaining, S3 used representational gestures by drawing imaginary lines from specific coordinate points to the y-axis and continuing to the x-axis. When verbalizing the coordinate points, S3 said, "*This is 4 ma'am… eh, this is 4 equals 2*" accompanied by hand movements depicting the mapping of values. These iconic gestures suggested that S3 experienced distraction when translating the coordinate points and organizing spatial information, leading to errors in reasoning. From a gesture analysis perspective, S3's actions involved a mixture of iconic gestures with tracing visible coordinate relationships and metaphorical gestures with attempting to express abstract relationships such as equivalence. However, not all gestures were productive; while some supported cognitive organization, others revealed confusion or instability in reasoning (Cook & Goldin-Meadow, 2006; Goldin-Meadow, 2003). The momentary switching between pointing and drawing gestures reflected S3's struggle to maintain conceptual consistency, marking these as partially productive gestures that served as transitional representations in the meaning-making process.

Furthermore, the researcher asked S3 about the differences and similarities with the first question, because of the characteristics of SL students who depend on others and are not confident in the skills they have previously had. S3 tried to connect one problem with another by describing diagram 2(a) like the first question in Figure 6 below.

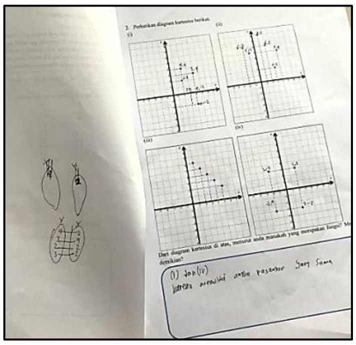


Figure 6. S3 Connecting The Second Question With The First Question

Figure 6 shows that S3 is able to apply the concept algorithmically to solve other problems even though it requires help from others. However, because S3's initial argument that the coordinates are (4,2); (3,4); (2,2) and so on, S3 changes its representation by crossing out and rewriting a new diagram as in Figure 6. This attempt showed cognitive engagement and relational reasoning, even though the initial understanding of coordinate pairs was flawed. Following Skemp (1978) indicators, S3 demonstrated an emerging ability to connect and reorganize concepts but had not yet developed the necessary and sufficient conditions for the function concept accurately. Thus, S3's gestures were interpreted as evidence of ongoing conceptual construction rather than conceptual mastery.

Subject 3

When solving the problem in question number two, S8 chooses answer (iv). As shown in Figure 7.

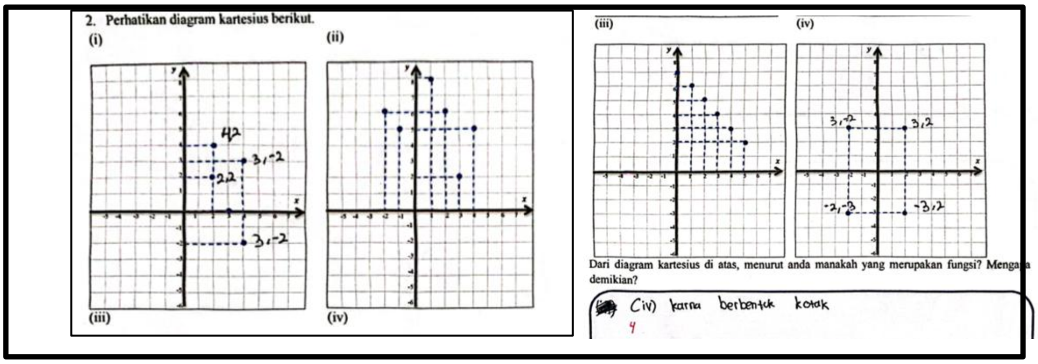


Figure 7. S8's answer results in the second question

In Figure 7, the reasons provided by S8 indicate that S8 had not yet developed a full understanding of the concept of a function. The results of the interview with the reasons for S8's answers were recorded by the researcher as in the following conversation.

P : What do you think, sir?
S8 : (reading softly while pointing to diagram 2 (iv))
which is this function, ma'am....
P : why did you choose that one, sir?
S8 : because this is a box, ma'am (while making a motion path (representational) connecting the points on the task sheet on graph 1 (iv)).

P : what about a box, sir?
S8 : Usually this is drawn on a line and then becomes a triangle, right…
(while making a motion path like forming a triangle)
P : try on a line, what do you mean?
S8 : Usually this is on line 5 and how many and then becomes like this, there are dots and then drawn on a line so it forms a box

Based on the conversation, it is indicated that when understanding the problem in question number two, S8 knows what is being asked in the question, namely which is a function and which is not a function. However, when pointing and explaining regarding his understanding, S8 mentions and points to the picture without a loud answer (stuttering) and not in accordance with what is being asked by the researcher. S8 seems not to be focused on the answer he gave, such as the word "*triangle*" which is expressed accompanied by a gesture forming a square in the air. This mismatch between gesture and verbal explanation reflects a distraction of thought and conceptual instability rather than understanding. Furthermore, to strengthen S8's understanding of the problem, the researcher tried to ask S8 again, as recorded in the following conversation.

P : Do you know what is meant by this question?
S8 : Which of the diagrams above is a function?
P : What is known first?
S8 : Cartesian diagram
P : Do you know the concept of a Cartesian diagram?
S8 : I know, ma'am, but I forgot...
P : Okay.. then what else do you think is known?
S8 : Which is a function?
P : Okay.. then
S8 : So what is the function, ma'am?

Based on the conversation, S8 seemed to have forgotten the concept of function previously discussed in the first question. In the first question, S8 was able to explain what a function was to the researcher, but in the second question, with the same question but with a different representational form of the function, S8 was unable to apply the concept algorithmically to solving a more complex problem. S8 was distracted by the Cartesian diagram he was facing so he forgot the concept of function that had been discussed in the previous question. The researcher asked S8 again to explore S8's understanding of the mathematical concept of function by linking the problem in the second question to the first question. As recorded in the conversation below.

P : What was the question number 1 that was asked earlier?
S8 : Which one has the function, ma'am
P : So it's almost the same, right?
S8 : Yes, ma'am (while scratching his head)
P : So what was your reason?
S : Because they're all in pairs, ma'am…
P : So… what about number 2?
S8 : This is ma'am, the 2(iv) one, because it's square, ma'am...
(while making a square-shaped track)

Based on the conversation, it indicates that S8 is distracted by the coordinate points which, if connected, will form a square, which S8 considers as a manifestation of a function that is paired with each other. The square-shaped movement produced by S8 was classified as a metaphorical gesture, symbolizing an attempt to represent a conceptual relationship rather than a literal one. However, following Cook and Goldin-Meadow (2006), such gestures are considered non-productive because they do not align with the mathematical structure being discussed. These gestures instead reveal cognitive struggle or failed retrieval, showing how students use embodied actions as scaffolds when verbal explanations are insufficient. S8's gesture functions more as a non-verbal communication tool to express difficulties than as proof of mature mastery of the concept. Based on what was conveyed by S8, it appears that the student's understanding of mathematical concepts in this second question is very limited, S8 is unable to classify objects based on whether or not the requirements for forming the concept are met and S8 is also unable to connect one concept with another. This can be seen from what was conveyed by S8. So S8 has not been able to develop the necessary requirements for a function concept because the understanding of the concept related to coordinate points on the Cartesian diagram is still wrong. According to Skemp (1978) framework, this suggests that S8 was unable to fulfill the indicators of conceptual understanding, such as classifying objects or connecting related concepts. His gestures, therefore, functioned as non-verbal attempts at reasoning rather than as evidence of conceptual mastery.

Based on the analysis of all three subjects, it was found that representational gestures consistently appeared during problem-solving; however, their functions varied depending on the students' cognitive state. Iconic gestures, which visually depicted concrete relationships, were generally productive and supported emerging understanding (as in S1 and S3). In contrast, metaphorical gesture particularly those not aligned with mathematical relationships, such as S8's "square" gesture were non-productive, signaling confusion or cognitive overload (Cook & Goldin-Meadow, 2006; Hostetter & Alibali, 2008).

Triangulation of observation, interview, and written data revealed that although SL students could externalize their reasoning through gestures, indicators of conceptual understanding object classification, concept connection, and formulation of necessary and sufficient conditions Skemp (1978) were only partially achieved. This finding supports the notion that gestures serve as scaffolds for meaning-making rather than definitive proof of conceptual mastery. The low self-efficacy, limited attention span, and verbal expression challenges typical of SL students further influenced the cognitive effectiveness of their gestures as learning tools.

Discussion

SL students' conceptual understanding was still very low. This limited conceptual understanding is the main reason why representational gestures performed by SL students are only symbolic and lack meaning, even though gestures are often used to help outline steps for solving problems (Gunawan et al., 2021). Without a clear conceptual understanding, gestures cannot function optimally as cognitive aids to visualize or organize mathematical concepts in depth. This is in line with research by Oktavianita and Wahidin (2022) which stated that SL students are limited in internalizing mathematical concepts. Research by Afan et al. (2021) and Ramadani and Khayroiyah (2021) also showed that SL students' conceptual understanding was very low, caused by a combination of intellectual limitations and low learning discipline, so that indicators of mathematical understanding were not met.

However, the findings of this study should not be interpreted as evidence that gesture use directly equates to conceptual understanding. Gestures, according to Cook and Goldin-Meadow (2006), can serve as indicators of both understanding and confusion reflecting transitional cognitive states or attempts at meaning-making rather than complete mastery. In this study, the gestures observed in SL students often represented efforts to build meaning through movement, particularly when verbal or symbolic reasoning was insufficient.

The results of this study indicate that the characteristics of SL students significantly influence the process of solving mathematical problems. Poor conceptual understanding is the main cause of the symbolic and inconsistent representational gestures produced by SL students, so that gestures cannot function optimally as cognitive aids in understanding abstract concepts (Oktavianita & Wahidin, 2022). SL students who tend to lack confidence in conveying ideas further limit their ability to express thoughts verbally and non-verbally (Chauhan, 2011). Furthermore, the low interest in learning found in some SL students is also related to limited conceptual understanding; a limited level of conceptual understanding affects their motivation to actively engage in the learning process (Yunuka, 2016). From the perspective of embodied cognition (Goldin-Meadow, 2003; Hostetter & Alibali, 2008), gestures are not merely communicative tools but serve as embodied extensions of thought that bridge internal cognition and external expression. In this study, SL students' gestures reflected how bodily movement was used to construct mental representations of mathematical ideas. Iconic gestures such as tracing paths or pointing to coordinate axes often represented concrete mappings and tended to be productive when they helped students visualize relationships between domain and codomain. Conversely, metaphorical gestures such as abstract or misaligned movements like S8's "square" gesture were often non-productive, signaling confusion or incomplete understanding.

Thus, gestures among SL students functioned as cognitive scaffolds that externalized their reasoning, not as confirmation of conceptual mastery. Productive gestures contributed to partial understanding by maintaining cognitive focus and linking concrete and abstract representations, while non-productive gestures revealed cognitive overload, uncertainty, or misclassification of concepts. This interpretation aligns with Alibali and Nathan (2012), who emphasize that gestures act as windows into learners' reasoning processes rather than as measures of correctness.

The results of this study provide a note for educators to pay more attention to the representational gestures produced by SL students. Teachers should interpret these gestures as diagnostic cues of students' ongoing meaning-making rather than as indicators of comprehension accuracy. Gestures produced by SL students are one way for them to communicate their difficulties in conveying ideas and the challenges they face.

Representational gestures serve more as non-verbal scaffolding to help focus and communicate thoughts, rather than as representations of mature concepts (Elvierayani & Kholiq, 2019). Therefore, initial conceptual understanding must be built first through the right learning approach so that the representational gestures produced by SL students can optimally strengthen their mathematical understanding and communication. The researcher hopes that with these findings, educators can determine learning strategies for SL students by using language and representations that are easy for them to remember, so that they are able to understand mathematical concepts more meaningfully. As obtained in this study, SL students more easily associate the concept of function with the language "not cheating." This verbal–gestural association illustrates how concrete language and embodied action jointly support partial meaning construction, even though full conceptual accuracy is not achieved.

This study strengthens the research of Wanabuliandari et al. (2025) suggesting that SL students require comprehensive and adaptive learning approaches, such as constructivist and embodied-based models supported by inclusive classroom environments. However, this study has limitations, including the small number of subjects (only three SL students), the limited number of problems given, and the focus on gesture analysis rather than instructional intervention. Therefore, the results should be interpreted cautiously as an initial exploration of how representational gestures reveal the meaning-making processes of SL students in mathematics learning.

Conclusion

The mathematical conceptual understanding of students identified as slow learners (SL) on the topic of functions is classified as limited. SL students are only able to classify objects based on the fulfillment of concept-forming requirements with the help of simple everyday language, allowing them to link concepts meaningfully. For example, the use of the term "non-cheating diagram" helps students understand the relationship between domains and codomains, indicating that everyday language can function as a cognitive bridge for understanding abstract mathematical concepts. However, the findings also reveal that representational gestures consistently appeared during problem-solving; however, their functions varied depending on the students' cognitive state. Iconic gestures, which visually depicted concrete relationships, were generally productive and supported emerging understanding . In contrast, metaphorical gesture particularly those not aligned with mathematical relationships, were non-productive, signaling confusion or cognitive overload.

This study highlights a new contribution by demonstrating how SL students use non-mathematical, everyday language and gesture together as compensatory tools to express and organize their mathematical reasoning. This combination underscores the embodied and multimodal nature of mathematical cognition, where language, gesture, and perception interact to scaffold conceptual learning. These findings suggest that strengthening initial conceptual understanding through simple, contextually meaningful language and visual–gestural representations can help SL students internalize mathematical concepts more effectively and inclusively.

This study has limitations, namely that it was conducted only on eighth-grade students, focusing on function material and representational gestures. Therefore, these findings cannot be generalized to other mathematical topics or student populations. Future research should explore how productive and non-productive gestures evolve across different mathematical domains and how teacher mediation influences this process. The practical implication of this study is that educators should interpret gestures as part of an ongoing cognitive dialogue rather than as definitive indicators of understanding. Teachers can use gestures and everyday language as diagnostic cues to identify areas of conceptual confusion and to design embodied, inclusive learning strategies that bridge abstract mathematical ideas with concrete experiences.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the authors have resolved ethical issues, including plagiarism, misconduct, falsification and/or fabrication of data, multiple publication and/or submission, and redundancy.

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Author Contributions

Rivatul Ridho Elvierayani: Review & editing, Conceptualization, Data analysis, Research methodology, and supervision; **Restu Lusiana**: Original draft writing, Data analysis and interpretation, Editing, and Visualization; **Beti Istanti Suwandayani**: Review & editing; **Ifroha Anita Silvia**: Data collector.

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