The Double-Edged Role of Visuals in Mathematics: A Cognitive Perspective on Deaf Learners

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Abstract

Deaf students often encounter difficulties in solving mathematical problems due to limited access to verbal explanations and abstract symbolic representations. Visuals are frequently introduced as a solution to support understanding, yet their effectiveness remains debatable. This study aims to explore the role of visuals in mathematics problems—whether they function as aids or obstacles in the cognitive processes of deaf learners. Employing a qualitative approach with a multiple case study design, the research involved 15 junior secondary school deaf students (7 females and 8 males) who were purposively selected based on the criteria of having no cognitive impairments or additional disabilities. Two mathematics teachers, one hearing and one deaf, were also involved. Data were collected through mathematics problem-solving tests followed by stimulated recall interviews to investigate students' cognitive strategies and visual interpretations. Data triangulation across sources and methods ensured the credibility of the findings. Results reveal that visuals can enhance conceptual understanding and assist in strategy planning, especially when images are simple, familiar, and directly related to mathematical content. However, visuals may also become cognitive distractions when they include irrelevant details, ambiguous symbols, or complex layouts. The study concludes that the effectiveness of visuals is highly dependent on their design and compatibility with students' visual literacy and representational skills. These findings underscore the importance of designing mathematics visuals that are cognitively accessible and pedagogically purposeful for deaf learners.

Keywords: pictorial math problem, deaf, cognitive load, problem solving, visual representation

Introduction

Mathematics is a discipline that heavily relies on abstract reasoning, symbolic representation, and linguistic precision. For deaf students, these features can present substantial barriers due to limited access to verbal explanations and the dominance of spoken and written language in instructional settings (Marcelino et al., 2019; Santos & Cordes, 2021). Consequently, many educators and researchers advocate the integration of visual representations—such as images, diagrams, and pictorial tasks—as a way to make mathematical content more accessible and concrete for students with hearing loss (Akay, 2021; Tanrıdiler, 2024).

The use of pictorial mathematics problems is increasingly popular in inclusive classrooms and special education settings. These visuals are expected to provide scaffolding for comprehension by translating abstract concepts into tangible, context-rich scenarios (Arcavi, 2003; Cooper & Alibali, 2012). However, while visuals may serve as cognitive aids, they can also act as cognitive distractors if not carefully designed. According to Cognitive Load Theory (CLT), poorly structured visuals can increase extraneous cognitive load, which hinders rather than supports problem solving (Sweller et al., 2019).

Deaf students, in particular, process information differently due to their reliance on visual-spatial modalities and signed languages. These unique cognitive profiles make them more sensitive to visual input, both in beneficial and adverse ways (Marschark et al., 2015, 2017). For example, a visual representation that is meaningful for hearing students may be misinterpreted by deaf students if it lacks clarity, cultural familiarity, or visual salience. Research has shown that while deaf students may excel in tasks involving visual memory and pattern recognition, they often struggle with tasks requiring transitions between representations, such as from visual images to symbolic notation (Crowe & Dammeyer, 2021).

Despite this, most existing studies treat visuals as inherently beneficial, with little attention to their dual potential as both facilitators and inhibitors of learning. This oversimplified view may lead to overuse or misuse of visuals in mathematics instruction, especially for deaf learners who already face a high cognitive load when decoding both linguistic and numerical information.

This study addresses this gap by exploring the double-edged role of visuals in mathematics problems from the perspective of deaf learners. Rather than assuming that visuals are always helpful, this research investigates the nuanced ways in which images influence cognitive processes—either by scaffolding mathematical thinking or by overwhelming students with irrelevant, confusing, or poorly aligned information. This perspective aligns with Duval's theory of semiotic representation, which emphasizes that the ability to transition between representations (e.g., from pictorial to symbolic) is a central component of mathematical understanding, and that failure to make these transitions can block cognitive development (Duval, 2006).

Furthermore, the study draws from the framework of Zone of Proximal Development (ZPD) and scaffolding, suggesting that visuals can function as temporary cognitive supports that must match the learner's developmental level (Thompson, 2023). If the design of visual tasks exceeds the student's current capacity to interpret and connect representations, then visuals may not act as scaffolds, but rather as obstacles that increase cognitive load and reduce performance.

While some previous research has examined how hearing students interpret visuals in word problems (Debrenti, 2015; Ma. Betty P, 2023), there is limited empirical research focusing on how deaf students experience and make sense of pictorial representations in mathematics, especially in a naturalistic problem-solving setting. Few studies integrate qualitative insights from student thinking—through think-alouds or stimulated recall interviews—to capture the cognitive mechanisms behind visual interpretation.

This study, therefore, aims to fill this gap by using a qualitative multiple case study approach involving 15 deaf students at the junior secondary level. Through a combination of mathematics problem-solving tasks and stimulated recall interviews, the research explores how visuals in mathematical tasks act either as cognitive supports or as sources of distraction. It also examines how students' strategies and interpretations vary depending on the nature and complexity of the visuals provided.

In doing so, this research contributes to a more critical and evidence-based understanding of visual design in mathematics education for deaf learners. Rather than adopting a one-size-fits-all approach to visual supports, it calls for more nuanced, pedagogically-informed visual design that considers cognitive accessibility, clarity of representation, and alignment with learners' strengths and limitations.

Ultimately, this study seeks to inform not only special education teachers but also curriculum designers and assessment developers in creating more effective visual mathematics materials that truly support learning rather than inadvertently hinder it.

To further investigate this dual role of visuals in mathematics learning, the present study focuses on how visual elements function either as cognitive aids or as sources of cognitive load during the problem-solving process. The study narrows its lens to explore two key questions:

1. In what ways do visuals serve either as cognitive supports or become barriers during mathematical problem solving?
2. What specific visual features contribute to either aiding or hindering the mathematical reasoning of deaf learners?

These questions aim to uncover not only the observable effects of visuals but also the characteristics of the visual representations (such as clarity, relevance, and layout) that impact learners' cognitive engagement. By concentrating on these dimensions, the study seeks to provide practical insights for educators and instructional designers to better tailor visual materials that are cognitively accessible and pedagogically effective for deaf students.

Literature Review

Deaf and Mathematics Learning

In educational research, the term "deaf" or "hearing-impaired" generally refers to individuals who experience partial or complete loss of hearing, which significantly impacts their ability to access spoken language. According to the World Health Organization (WHO), hearing loss is categorized based on severity (mild, moderate, severe, or profound) and may occur in one or both ears (Olusanya et al., 2019; World Health Organization, 2021). In the educational context, deafness is not only a medical condition but also a cultural-linguistic identity, particularly among individuals who use sign language as their primary mode of communication (Higgins, 2016). Table 1 below is a categorization of deaf people based on the level of hearing loss.

Tabel 1 Level of Hearing Loss

Degree of Hearing Loss	Hearing Threshold (dB)	Description
Mild	26 – 40 dB	May have difficulty hearing faint speech or in noisy environments.
Moderate	41 – 60 dB	Difficulty hearing normal speech without hearing aids.
Severe	61 – 80 dB	Cannot hear most conversational speech; relies heavily on visual input.
Profound	81 dB or greater	May not hear even loud sounds; communication primarily through sign language.

In Indonesia, communication in mathematics classrooms for deaf students often involves a combination of Sistem Isyarat Bahasa Indonesia (SIBI)—a manual signing system that follows the structure of spoken Indonesian— and gerak bibir (lip movements) to complement meaning. In mathematics learning, this combination is frequently used to explain abstract concepts, describe problem-solving steps, and support comprehension of verbal instructions.

Deaf students encounter unique challenges in mathematics learning due to their limited access to spoken language and auditory explanations, both of which are central to conventional mathematics instruction. Mathematics often requires learners to understand symbolic representations, abstract reasoning, and multi-step problem solving—areas where verbal explanations typically play a key role. Because deaf students often rely on visual-spatial modalities and signed languages, they develop different cognitive profiles that influence how they perceive and process mathematical information (Buyle & Crollen, 2022; Henner et al., 2021).

Research suggests that while deaf students may demonstrate strengths in visual memory, spatial reasoning, and pattern recognition, they often struggle with understanding complex instructions and transitioning between different mathematical representations, especially those involving verbal or symbolic text (Kelly et al., 2022). The mismatch between traditional instructional methods and the cognitive-linguistic needs of deaf learners contributes to ongoing disparities in mathematics achievement (Pagliaro & Kritzer, 2013; Swanwick et al., 2016).

To mitigate these challenges, many educators turn to visual supports—such as pictorial representations, diagrams, and color-coded symbols—to scaffold learning. However, while visual tools are commonly perceived as inclusive, their design and implementation require careful consideration to ensure they align with the learners' processing abilities.

Visual Representation in Mathematics Education

Visual representation refers to the use of non-verbal, graphical elements—such as diagrams, charts, number lines, models, illustrations, or spatial layouts—to express, explain, or explore mathematical ideas (Arcavi, 2003; Stylianou & Silver, 2020). These representations help bridge abstract mathematical concepts and learners' concrete understanding by offering alternate modes of thinking beyond symbols and text.

In mathematics education, visual representations are classified into several types, including:

1. Concrete representations (e.g., manipulatives, real-life images),
2. Pictorial representations (e.g., drawings, simplified visuals),
3. Abstract representations (e.g., graphs, geometric diagrams, symbolic notation)

Duval (2006) emphasizes that understanding mathematics depends not just on knowing individual representations, but on the ability to coordinate and convert between representations. Thus, visuals are not only aids for illustration but are central to mathematical reasoning and problem solving.

In this study, pictorial math problems are defined as mathematical word problems enhanced with context-relevant visual images, aimed at assisting deaf students' comprehension of operations, quantities, and relationships by leveraging their strength in visual-spatial reasoning. The role of these visuals is examined critically—not as inherently beneficial, but as potential cognitive scaffolds or sources of overload, depending on their design and alignment with the learner's cognitive and linguistic profile.

Cognitive Load Theory

The Cognitive Load Theory (CLT) provides a useful framework for evaluating the impact of visuals on learning. CLT distinguishes between three types of cognitive load:

1. Intrinsic load, related to the inherent complexity of the content;
2. Extraneous load, caused by poor instructional design or irrelevant information; and
3. Germane load, which refers to the mental effort dedicated to meaningful learning and schema construction (Sweller, van Merriënboer, & Paas, 2019).

Visuals can either reduce extraneous load by simplifying complex information or increase it by introducing unnecessary elements. For example, a pictorial problem with crowded visuals or unfamiliar context can overload a learner's working memory, especially if the learner is also translating between visual and symbolic forms (Schnotz & Kürschner, 2007).

For deaf students, who already face linguistic processing constraints, excessive or ambiguous visuals can be cognitively taxing. Therefore, designing visual tasks for these learners requires an instructionally efficient approach—one that reduces visual clutter, highlights essential information, and matches learners' representational fluency.

Scaffolding and the Zone of Proximal Development

The concept of scaffolding, rooted in Vygotsky's (1978) theory of the Zone of Proximal Development (ZPD), is particularly relevant when considering the function of visuals in deaf education. Scaffolding refers to temporary instructional supports that help learners perform tasks they could not accomplish independently. Visuals can act as scaffolds when they help bridge the gap between the learner's current understanding and the intended learning target.

However, scaffolds are only effective when they are calibrated to the learner’s level of development. If a visual exceeds the learner's ability to interpret it—due to unfamiliarity, symbolic complexity, or poor alignment with prior knowledge—it can create frustration rather than support. Hammond and Gibbons (2005) assert that successful scaffolding involves both reducing complexity and enhancing engagement through structured, meaningful supports. For deaf students, this means that visual scaffolding must consider not only content accuracy, but also visual clarity, familiarity, and cultural accessibility

Methodology

Research Design

This study employed a qualitative approach with a multiple case study design to explore how deaf students experience and interpret visual elements in mathematics problems. The case study design was chosen to enable in-depth, contextually rich investigation of individual learners, while also allowing for cross-case comparisons to identify recurring patterns or variations in cognitive responses (Yin, 2018). The study focuses on understanding how pictorial representations in mathematics tasks function either as cognitive scaffolds or as sources of cognitive load, particularly in arithmetic problem solving. The design integrates test-based tasks and stimulated recall interviews to gain access to the students’ internal reasoning processes, including moments of difficulty, misunderstanding, or successful strategy use.

Participants and Research Setting

The participants consisted of 15 deaf students at the junior secondary school level (equivalent to Grades 7–9), comprising 7 females and 8 males. All students were selected through purposive sampling based on the following criteria.

1. Diagnosed with severe to profound hearing loss without any additional cognitive or sensory impairments.
2. actively using SIBI (Sistem Isyarat Bahasa Indonesia) and lip movements as their primary modes of classroom communication.

In addition to the students, two mathematics teachers were also involved (one hearing and one deaf teacher) to provide contextual insight regarding instructional strategies and student behavior. The research was conducted in a state special needs school (SLB-B) located in Magelang, Central Java, Indonesia. The school provides inclusive mathematics education that integrates visual learning strategies and uses sign-based communication systems.

Data Collection

Two primary methods were used to collect data.

1. Mathematical Problem-Solving Test (with illustration)
   Students were asked to complete a series of pictorial word problems designed to represent realistic and supportive images. The tasks focused on basic arithmetic operations—addition, subtraction, multiplication, and division. During the test session, students were observed and encouraged to indicate parts of the image that helped or confused them.
2. Stimulated Recall Interviews
   Using selected video segments, the researcher invited students to reflect on their reasoning, explain the visual elements they attended to, and describe whether the images supported or hindered their thinking. Interviews were conducted semi-structurally, using prompts adapted into simple Indonesian sign language or supported with interpreters to accommodate students’ communication needs. This method allowed for exploration of cognitive processes that could not be captured through test results alone (Gass & Mackey, 2017).

Research Procedures

Preparation

The researcher designed and validated the pictorial tasks with input from mathematics and special education experts to ensure conceptual and cognitive equivalence between visual and non-visual elements. A pilot study was conducted with two non-participant students to test the clarity of instructions and image readability.

Data Collection Session

Each student participated in one individual session consisting of:

1. A pictorial math test
2. Followed by a video-based stimulated recall interview

Teacher Interviews

Two teachers were interviewed using semi-structured protocols to gather perspectives on the use of visuals in mathematics instruction, typical student strategies, and communication patterns in class.

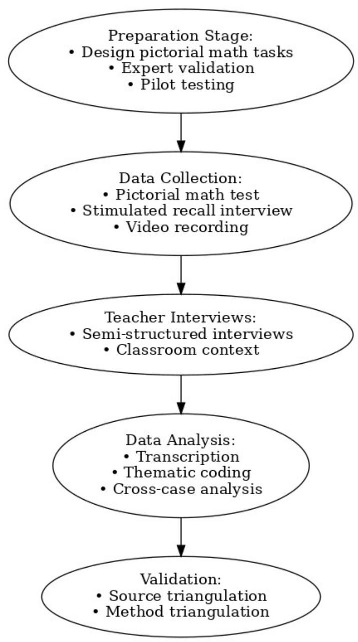

Figure 1. Research Procedures

Data Trustworthiness Techniques

To ensure the trustworthiness and credibility of the data, this study employed two key strategies commonly used in qualitative research: source triangulation and method triangulation (Lincoln & Guba, 1985).

Method triangulation was carried out by combining multiple techniques for data collection, including:

1. student responses to pictorial math tests
2. stimulated recall interviews

These different methods provided complementary perspectives on the same phenomenon, allowing the researcher to cross-check and interpret cognitive patterns more robustly.

Source triangulation was implemented by collecting data from multiple informants. This included the 15 deaf students and two mathematics teachers (one hearing, one deaf), which enabled the comparison of perspectives between students' actual cognitive experiences and teachers' observations of classroom behavior and strategies. These multiple viewpoints enriched the interpretation and ensured that the findings reflected a broader understanding of how visuals function in the learning process of deaf students.

Together, these triangulation techniques contributed to establishing the validity and depth of the qualitative findings while minimizing potential researcher bias.

Results

The analysis in this study was grounded in students' responses to a set of carefully designed pictorial mathematics problems focused on the topic of length measurement using standard rulers. Each item presented a visual representation of a ruler with varying starting points, tick mark intervals, and measurement contexts. These tasks were purposefully constructed to examine how deaf students interpret, process, and reason with visual cues embedded in mathematical representations.

Through the use of both test responses and stimulated recall interviews, the students' thinking processes were traced and coded. The questions required students to not only recognize numerical values but also to determine lengths based on visual intervals and scales. This format allowed the researcher to explore the interplay between visual design and students' problem-solving strategies, particularly in identifying whether visuals served as cognitive aids or barriers. Figure 1 below is the question used translated into English.

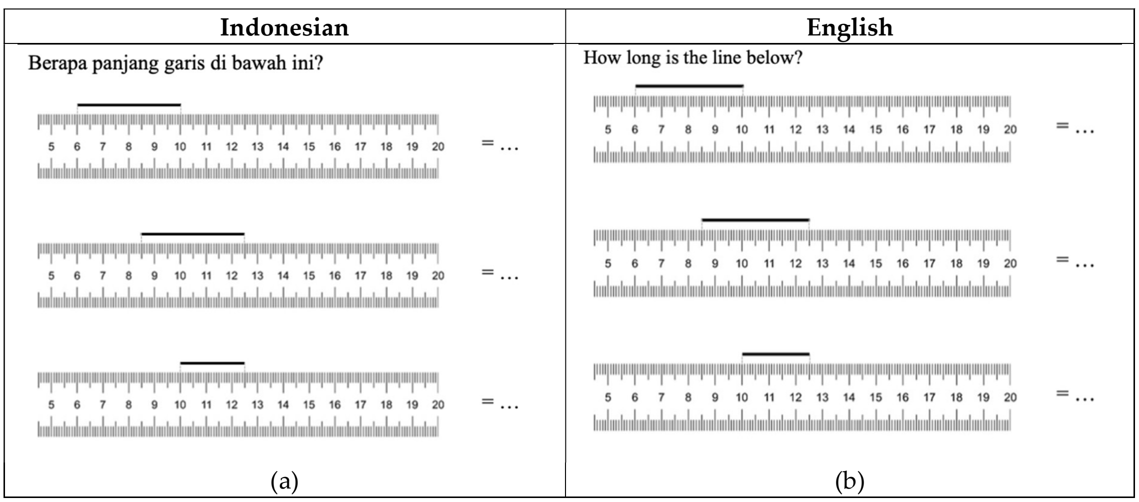

Figure 1 Problem in (a) Indonesian (b) English

Based on the bilingual pictorial items presented in Figure 1, several key findings emerged concerning how deaf students interpreted and reasoned with visual representations during length measurement tasks. These findings were derived from test responses and stimulated recall interviews, which revealed students' strategies, recurring errors, and cognitive perceptions of the visual elements used in the problems.

The following results are organized into four major themes that capture the double-edged role of visuals as both cognitive support and cognitive load in deaf students' mathematical thinking.

Visuals as Cognitive Scaffolding: Segmenting Space and Clarifying Distance

Several students demonstrated that the ruler image provided functioned as an effective cognitive scaffold in supporting their understanding of length measurement as the difference between two points. For instance, students M3, Mo1, and S2 employed active visual strategies such as drawing arcs, pointing directly at tick marks, or explicitly identifying the start and end points to determine length differentials. An example of a curved line made by the subject is as shown in Figure 2 below.

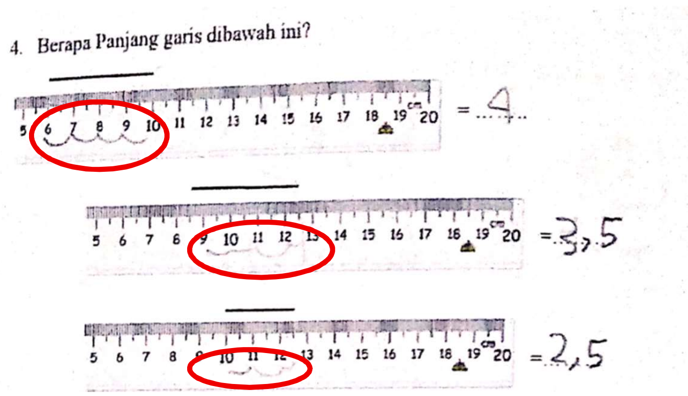

Figure 2 The result of M3

Based on the results of the work, subject M3 explained that the strategy used was intended to mark the extent of the measurements that had been taken. The following is an excerpt from an interview with M3. "I drew a line so I wouldn't forget where I had reached," said M3.

The adoption of these strategies suggests that students were capable of transforming visual input into internal spatial representations, thereby reducing cognitive load in working memory. Visuals featuring high contrast, consistent tick mark intervals, and logical spatial order were particularly supportive in facilitating accurate length estimations. Notably, some students who initially made errors (such as M3) were able to self-correct upon re-examining the visual during the stimulated recall session.

These findings support the proposition that well-designed visual representations, when coupled with appropriate instructional strategies, can serve as effective scaffolding tools that enhance students' mathematical reasoning processes.

Visuals as Cognitive Load: When Design Becomes Distracting

On the other hand, the same visual representation imposed a cognitive burden on some students. When the visual design did not align with students' logical expectations or contained ambiguous elements, such as a scale that did not begin at zero or a half-centimeter tick mark that was too small. The image became an obstacle to comprehension rather than a support. The following is an excerpt from an interview with M1 and Mo2.

"Why doesn't the ruler start from zero?" (M1)
"I didn't see the half mark..." (Mo2)

Students M1 and S1 developed misconceptions by treating the endpoint as the starting point, failing to recognize that the correct measurement was from point 9 to 12.5 (rather than simply interpreting the number 12 as the length). Meanwhile, Mo2, Mo3, and Mo4 encountered difficulties interpreting the ½ cm tick mark, which was either too small or lacked sufficient visual contrast. As a result, despite the simplicity of the operation, their length estimations were incorrect.

Visuals became cognitively demanding when:

- They were overly complex without cognitive emphasis.
- They failed to clearly indicate the starting and ending points.
- They lacked accompanying verbal context to guide interpretation.

These findings indicate that visual design must consider both legibility and alignment of spatial structure with students' logical reasoning, particularly for deaf students who rely heavily on visual modalities for learning.

Notation Traps: When Concepts Are Clear but Symbols Mislead

Some students demonstrated a sound understanding of the concepts of measurement and length difference, yet were still assessed as incorrect due to errors in symbolic notation or unit representation. The most notable case was Mo1, who answered all items correctly in terms of logic but misplaced the equals sign ("=") or omitted the unit "cm."

"I think everything was correct, I just forgot to write 'cm'." (Mo1)

This situation exemplifies a notation trap—a condition in which the error stems not from a conceptual misunderstanding but from the way the answer is presented. Such errors are common among deaf students who have not received explicit instruction on mathematical notation conventions, such as proper placement of the equals sign or consistent use of measurement units.

The implications are as follows:

- Teachers must provide explicit instruction in mathematical notation awareness.
- Assessment of deaf students' mathematical learning should prioritize conceptual understanding over formal correctness in symbolic representation.

Strategic Variability and Social Scaffolding

Not all students utilized visual representations effectively. Students such as M4 and Mo4 chose to disregard the images and instead relied on verbal memory or peer assistance. This reflects variations in learning strategies and a reliance on social scaffolding when visual scaffolds were perceived as unhelpful.

"I didn't understand the image, so I just asked a friend". (M4)
"I forgot this was a half… I just looked at the numbers". (Mo4)

These observations suggest the following:

- Some students have not yet developed mathematical visual literacy.
- The absence of visual interpretation strategies led them to avoid images, even when those images were intentionally designed to support understanding.
- Stimulated recall interviews were effective in eliciting student reflections on what aspects were confusing and how they chose to respond.

These findings underscore the importance of explicit training in the use of visual aids, as well as the development of metacognitive skills to enable students to evaluate and regulate their own learning strategies.

Summary of Findings

The analysis revealed four key themes that describe how deaf students engaged with visual representations during mathematical problem solving. These themes reflect not only the cognitive benefits and challenges associated with visual tools but also highlight the variability in students' strategies and the influence of formal notation. A detailed summary of the findings is presented Table 2 below.

Table 2 Summary of Findings

Theme	**Detailed Explanation**
Visual as scaffolding	Visual representations were beneficial when the images were clearly designed, included explicit starting and ending points, and were accompanied by spatial interpretation strategies.
Visual as cognitive load	Visuals became a cognitive burden when the design was unintuitive—such as scales not starting at zero or overly small tick

	marks—or when students lacked effective strategies for visual interpretation.
Notation traps	Some students demonstrated sound conceptual understanding but made errors in symbols or units. These mistakes stemmed not from faulty reasoning but from formal aspects of answer expression.
Strategic variability	Differences in the use of visuals reflected variability in cognitive strategies and visual literacy. Some students relied on peers or chose to ignore the visuals entirely.

Discussion

Visuals as Cognitive Scaffold: Segmenting Space and Clarifying Distance

This study found that several deaf students were able to use visual elements in mathematics tasks as cognitive scaffolds that helped clarify relationships between quantities, particularly in problems involving length measurement. Students like M3, Mo1, and S2 applied visual segmentation strategies, such as drawing curved lines or pointing at tick marks, to calculate distances between two points. These behaviors demonstrate the potential of visual representation to externalize abstract operations, such as subtraction, and make them concrete through spatial reasoning.

Arcavi (2003) emphasized that visual representations in mathematics are not just decorative, but can function as essential tools for thought, particularly when they help learners build and manipulate mental models. In this study, students who could interpret the function of the ruler image (not simply as a static object but as a representation of difference or change) were more successful in reasoning through the task. One student said, "I used the arc so I won't get lost in the numbers," indicating the role of self-directed visual strategies in maintaining attention and logic.

Furthermore, students who engaged in these strategies were often able to self-correct during the stimulated recall interviews. For example, M3 initially miscounted the segment, but after watching her own recording and being prompted, revised her reasoning and concluded, "Oh, I forgot to start from here [pointing to 9], not from 10." This highlights the importance of reflective scaffolding, in which the combination of visual tools and metacognitive guidance promotes deeper understanding (Stylianou & Silver, 2020).

These findings support the claim that visuals (when appropriately designed and accompanied by opportunities for strategic use) can reduce intrinsic and extraneous cognitive load (Sweller et al., 2019), especially for students with strong visual learning preferences, such as deaf learners. In short, visual representation can be more than a comprehension aid, it becomes an active participant in the problem-solving process.

Visuals as Cognitive Load: When Design Becomes Distracting

Despite the positive potential of visuals, this study also revealed that design flaws or ambiguous visual elements led to significant confusion and cognitive overload among other students. For instance, students M1 and S1 mistakenly assumed that measurement began at the end of the line, because the ruler image did not start at zero. Others, such as Mo2 and Mo4, misread the small tick marks representing 0.5 centimeters, resulting in incomplete or incorrect answers. These visual elements, intended to support, instead became obstacles to learning.

This supports the view of Schnotz and Kürschner (2007), who argue that visuals can increase cognitive load when they are either too dense, too sparse, or not aligned with task demands. In mathematics problems, especially for learners who rely on visual cues, any misalignment between representation and expectation can lead to misinterpretation of problem structure. As one student (M1) said, "Why doesn't the ruler start from zero? It makes it hard to know where to begin." This statement reflects a mismatch between the visual input and the learner's schema.

Moreover, the ambiguity of decimal representation in the ruler, such as small and barely visible tick marks for 0.5 cm, added a layer of uncertainty. Students like Mo3 stated, "I thought that line was just decoration... I didn't realize it meant half." Such interpretations suggest that without explicit orientation, students may fail to integrate key mathematical features presented in the image. This reinforces the claim by Sweller et al. (2019) that extraneous load—information that does not aid understanding but must still be processed—can hinder learning.

Therefore, the findings stress the importance of visual clarity, saliency, and alignment with mathematical goals. If visuals are to serve their intended function, educators and designers must prioritize simplicity and perceptual accessibility over aesthetic appeal. For deaf students in particular, where visual attention is heavily taxed, every element in a visual must be intentional and informative (Marschark & Knoors, 2022).

Notation Traps: When Concepts Are Clear but Symbols Mislead

Another key insight from this study is the discrepancy between correct conceptual understanding and errors in written notation, particularly in the use of mathematical symbols and measurement units. Student Mo1, for instance, accurately calculated the lengths in all three problems but wrote the results with incorrect syntax, such as placing the equal sign before the number or omitting the unit "cm." When asked, the student replied, "I just forgot to write the cm… but I got the numbers right." This reflects a common phenomenon in deaf education—conceptual comprehension is not always matched by formal expression.

Notation issues like these have been noted in the work of Brill et al. (2020), who state that deaf students often struggle with syntactic elements of mathematical language due to limited exposure to spoken formalities. Moreover, since SIBI (Sistem Isyarat Bahasa Indonesia) and BISINDO (Bahasa Isyarat Indonesia) often omit or rearrange word order compared to written Indonesian, there can be mismatches between internal reasoning and written output. Thus, failure to write "12.5 cm" or to format an equation properly may not reflect a lack of understanding, but a gap in communication norms.

This highlights the need for educators to teach mathematical notation explicitly, not just as a formality, but as part of mathematical meaning-making. Just as visuals must be interpreted, so too must symbols be constructed as meaningful. Without this instruction, students may lose marks for reasons unrelated to their actual reasoning, which undermines both assessment validity and learner confidence.

Ultimately, these findings call for a dual focus in teaching: strengthening conceptual foundations while also training students in clear, conventional mathematical communication. For deaf students, who are often visual and spatial thinkers, this balance must be carefully designed into instructional materials and assessment strategies.

Strategic Variability and the Role of Metacognition

The study also uncovered significant variability in how students used visual aids, with some students actively engaging with the visuals and others completely ignoring them. For example, student M4 did not attempt to interpret the image and instead said, "I asked my friend because I didn't get the picture." Similarly, Mo4 ignored the half-centimeter tick and relied only on whole numbers. These responses suggest that while visuals are available, not all students are equally equipped to use them strategically.

This supports research by Stylianou and Silver (2020), which suggests that visual literacy is not innate, but must be cultivated through experience and instruction. Students who did not engage with visuals may lack the skills or confidence to extract meaning from them, or may have developed alternative strategies such as memorization or verbal estimation. For some, the images may even be perceived as distracting or irrelevant, especially if they were not taught how to map visuals onto mathematical concepts.

Interestingly, some students revised their misconceptions after participating in the stimulated recall interview, a method that asked them to reflect on their problem-solving process while watching a video of their own actions. Student S2, who initially misread the tick marks, later stated, "Oh, I get it now—this part means half, so it's two and a half, not three." This shows that reflective opportunities can help students align perception with reasoning, and correct misconceptions.

These insights align with Vygotsky's (1978) Zone of Proximal Development (ZPD), which emphasizes the importance of guided interaction and scaffolding in learning. In this case, visual scaffolds functioned best when paired with social or metacognitive scaffolds—such as peer explanation, teacher prompting, or reflective recall. For deaf learners, whose access to incidental learning may be limited, such intentional scaffolding is essential for developing autonomous mathematical thinking.

General Overview

This study revealed the complex and dual nature of visual representations in mathematics problem-solving among deaf students. While some participants benefited from the presence of images—especially when using segmenting strategies and visual scaffolds—others experienced confusion due to ambiguous design elements. These results suggest that visuals in mathematics are not inherently beneficial or harmful; rather, their effectiveness depends on how they are designed, interpreted, and integrated into instruction. The same ruler image, for instance, was perceived as helpful by one student and confusing by another, illustrating how individual differences, prior experience, and clarity of visual structure play a crucial role.

The findings also emphasize the importance of explicit instruction in mathematical communication, especially regarding notation and conventions. Several students who demonstrated sound reasoning still produced incorrect written answers due to misplaced symbols or omitted units. This points to a broader issue in deaf education—the disconnect between conceptual understanding and symbolic expression—that may not be due to cognitive limitations, but rather to gaps in formal mathematical language exposure. Addressing this gap requires teaching strategies that integrate visual, symbolic, and linguistic scaffolding explicitly and inclusively.

Finally, the study highlights the need for metacognitive and strategic support for deaf learners. Some students effectively revised their thinking during stimulated recall interviews, suggesting that reflection and self-awareness can be powerful tools in strengthening mathematical understanding. However, others showed overconfidence in incorrect answers or relied on peers instead of visuals. This variability underlines the importance of cultivating visual literacy and metacognitive skills through structured instruction, reflection opportunities, and teacher feedback. Ultimately, the results call for an inclusive pedagogical approach that does not merely provide visuals, but ensures that students know how to make sense of and use them meaningfully.

Conclusion and Recommendation

This study investigated how deaf students engage with pictorial mathematics tasks and how visual elements function as either cognitive scaffolds or cognitive loads during problem-solving. Visuals were most effective when they were clear, appropriately scaled, and paired with strategies such as visual segmentation, which helped students conceptualize mathematical operations like measurement as spatial relationships. However, poorly designed visuals—such as rulers not starting at zero or unclear fractional tick marks—introduced extraneous cognitive load, leading to systematic misunderstandings. Furthermore, while some students demonstrated strong conceptual understanding, their performance was undermined by notation errors, such as incorrect use of mathematical symbols or omission of units.

These findings reinforce the idea that deaf students, as predominantly visual learners, benefit from structured and accessible visual representations, but also require direct instruction on how to interpret, apply, and communicate using such visuals. The study also emphasizes the role of metacognitive support, including reflective tools like stimulated recall, to help students evaluate and revise their problem-solving approaches.

In conclusion, visuals are not inherently helpful or harmful in mathematics instruction for deaf students. Their effectiveness depends on design quality, pedagogical integration, and the extent to which students are taught to engage with them meaningfully. Future research should explore longitudinal interventions that combine visual scaffolding with explicit strategy instruction, and examine how these approaches influence broader mathematical understanding across different topics and levels of hearing loss.

Conflict of Interest

The authors declare that there is no conflict of interest.

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