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Linguistic, Conceptual, and Procedural Interference in Junior High School Students' Solutions to Similarity Word Problems: A Qualitative Study

Sabar Dewantara[1]*, Purwanto[2], Slamet[1]
[1]Mathematics Education Program, Faculty of Teacher Training and Education, Malang State University, Central java, Indonesia
*sabar.dewantara.2503118@students.um.ac.id

ABSTRACT

Junior high school students consistently exhibit systematic errors when solving similarity word problems. However, the cognitive mechanisms underlying these errors remain underexplored across linguistic, conceptual, and procedural dimensions. This study explores cognitive interference experienced by eighth-grade students solving similarity problems designed according to Indonesia's Academic Competency Test (TKA) characteristics, using a complex multiple-choice format allowing multiple answers. A descriptive-exploratory qualitative approach involved eight participants selected through two-stage written screening and examined through think-aloud interviews. Data were analyzed using Miles, Huberman, and Saldaña's interactive model, supported by triangulation, member checking, and audit trails. Findings reveal three forms of cognitive interference: linguistic interference arising from insufficient semantic inhibition when interpreting distributive phrases; conceptual interference triggered by natural number bias and misconceptions about corresponding sides; and procedural interference resulting from dominant algorithmic schemas and procedural degradation under working memory constraints. In two participants, these forms developed into a hierarchical causal cascade, whereby linguistic interference triggered conceptual interference, subsequently leading to procedural interference. Several participants demonstrated an illusion of understanding, producing correct answers despite flawed reasoning. These findings highlight the importance of verifying cognitive processes through interviews rather than relying solely on final answers, providing a diagnostic foundation for adaptive mathematics assessment and instruction.

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SUBJECT

Mathematics Education, Mathematical Cognition, Mathematical Problem-Solving

1. Introduction

Mathematical literacy, numeracy, and problem-solving are strategic indicators of a country's education system quality. Programme for International Student Assessment (PISA) results over the past decade show that Indonesian students' achievements remain in the relatively low category, particularly in reasoning and contextual problem-solving aspects. In PISA 2022, the average mathematics score of Indonesian students was only 366, far below the OECD average of 472, with only 18% of students reaching level 2 and above, and almost

none reaching levels 5–6, which indicate high-level mathematical modeling abilities [1]. In response, the Ministry of Primary and Secondary Education through Regulation Number 9 of 2025 implemented the Academic Ability Test (TKA) which structurally adopts PISA test characteristics, including complex multiple-choice (CMC) format with more than one correct answer [2]. While these broad national assessments highlight a general deficit in mathematical reasoning, they do not directly isolate the specific micro-level cognitive mechanisms at play in classroom settings.

Mathematical word problems are the most representative format for revealing the complexity of students' thinking because they demand simultaneous integration of linguistic, conceptual, and procedural abilities, thus potentially revealing thinking obstacles not apparent in routine problems [3]. In similarity material, previous research has identified three main sources of errors: (1) assessing similarity based on visual resemblance without verifying side ratios, consistent with the Van Hiele visualization stage dominant in students [4], [5]; (2) excessive information load in word problems causing wrong schema and cognitive overload [6], [7], [8]; and (3) weak inhibitory control under time pressure that encourages linear overgeneralization in non-linear contexts [9], [10].

These conditions create opportunities for cognitive interference to emerge, namely disruptions in thinking processes when old knowledge or irrelevant strategies actually hinder new information processing [11], [12], [13]. In mathematics, cognitive interference manifests in three dimensions: linguistic interference (failure to interpret problem language), conceptual interference (dominance of old understanding that blocks new concepts), and procedural interference (application of familiar algorithms that do not match the problem structure) [12], [14]. A preliminary study of 38 eighth-grade students in one junior high school in Kediri City showed indications that all three forms of interference appeared in students' answers, aligning with Maarial et al.'s [15] findings that junior high school students' errors in similarity word problems are systematic and encompass all three stages simultaneously.

Previous research has made important contributions but tends to examine one or two dimensions of interference separately: conceptual interference in permutation-combination [14], semantic and procedural interference in comparison [12], procedural interference in arithmetic-geometric sequences [16], and proactive interference in comparison problems [17]. In the similarity context, Maarial et al. [15] confirmed three-stage systematic errors without revealing the cognitive mechanism explaining the interrelationship between stages, while Muna et al. [18] identified persistent similarity misconceptions through three-tier diagnostic tests without placing them in a cognitive interference framework. Based on a systematic review of literature published between 2019 and 2025 focusing on mathematics education and cognitive psychology, no research has been found that simultaneously maps all three dimensions of cognitive interference in one similarity word problem context based on TKA CMC format characteristics through an exploratory qualitative approach that reveals cognitive mechanisms in depth. The CMC format is expected to reveal interference differently from conventional single-answer problems because evaluating multiple statements simultaneously increases working-memory demands and exposes students to multiple distractors that can trigger distinct linguistic, conceptual, or procedural disruptions.

Based on these gaps, this study aims to describe the forms of cognitive interference in eighth-grade junior high school students in solving similarity word problems, their mechanisms and consistency across problem contexts, and the interrelationships between

these forms of interference. The novelty of this research lies in the simultaneous mapping of three interference dimensions through a two-test design with equivalent cognitive structures but different surface contexts, combined with think-aloud interviews to distinguish genuine cognitive interference from mere lack of conceptual knowledge. Specifically, this study addresses the following research questions: (1) What forms of cognitive interference emerge when eighth-grade students solve similarity word problems in a CMC format? (2) Are these interference patterns consistent across different problem contexts? (3) How do linguistic, conceptual, and procedural interferences interact or sequence themselves during the problem-solving process?

2. Literature Review

2.1 Cognitive Interference in Mathematics Learning

Mathematics learning is hierarchical, cumulative, and continuous because new knowledge is always built upon previously acquired knowledge structures [19]. However, under certain conditions, old schemas stored in memory can hinder the reception, processing, and use of new information when collisions occur between old representations and new conceptual demands. Anderson & Neely [20] defined this condition as interference—a cognitive disruption that occurs when old information inhibits the use of relevant new information. Macleod [21] emphasized that interference is the primary cause of forgetting and learning obstacles, operating through two mechanisms: proactive interference, where old knowledge hinders the processing of new information, and retroactive interference, where new knowledge disrupts the memory of old knowledge. It is important to distinguish established findings in the cited literature from the hypotheses used to interpret the present cases. For instance, while weak semantic inhibition and working-memory degradation are theoretically plausible, they require specific operational criteria to be inferred from student work.

2.2 Dimensions of Cognitive Interference

In the context of mathematics learning, cognitive interference is not merely computational errors or simple procedural mistakes but indicates structural barriers in students' thinking processes [12]. Researchers have proposed categorizations to map the dimensions of interference more operationally. Sukoriyanto et al. [14] differentiated interference based on the dominant knowledge disrupted: conceptual interference and procedural interference. Irfan et al. [12] expanded this categorization by adding a semantic-linguistic dimension disruptions stemming from errors in interpreting the meaning of problem language as a distinct dimension mechanistically different from conceptual or procedural disruptions.

Izzananda et al. [16] further emphasized the separation of procedural from conceptual dimensions, arguing that failure to choose the appropriate algorithm can occur even when students have adequate conceptual understanding, thus requiring separate examination. Based on synthesis of previous research dimensions, cognitive interference in this context is classified into three main forms: (1) linguistic interference, (2) conceptual interference, and (3) procedural interference. These three forms reflect different cognitive stages in mathematical word problem solving: language comprehension stage, conceptual model formation stage, and mathematical strategy execution stage [15].

2.3 Linguistic Interference in Mathematical Word Problems

Linguistic interference represents the earliest form of disruption in mathematical word problem solving, occurring during the language processing phase before students enter mathematical thinking. Strohmaier et al. [22], through eye-tracking research, found that linguistic difficulties affect students' attention patterns from the early reading phase, long before computation begins, and these disrupted attention patterns directly correlate with final solution errors.

The primary source of linguistic interference in mathematics is semantic ambiguity conditions where mathematical terms have technical meanings different from everyday meanings already internalized in students' cognition. Maanu & Asare [23] explained that "false friends" or semantic ambiguity often becomes the main cause because mathematical terms like "proportional," "corresponding," or "similar" are interpreted based on everyday meanings rather than their formal mathematical definitions, creating an illusion of understanding that subtly undermines the solution process.

The mechanism of linguistic interference is closely related to weak inhibitory control at the semantic level. Jaffe & Bolger [24] confirmed that lexical inconsistency in word problems where words superficially point to operations different from those actually required consistently increases student errors, and inhibition ability is critical in suppressing automatic responses provoked by misleading relational words. Palmer et al. [10] added that semantic inhibition, a subcomponent of inhibition specifically working during problem language processing, directly predicts linguistic interference when weak.

2.4 Conceptual Interference in Proportional Reasoning

Conceptual interference occurs during the formation of mathematical representations when students attempt to understand the relational meaning of problems and build appropriate conceptual models. Irfan et al. [12] explained that conceptual interference emerges when seemingly relevant knowledge structures prove inappropriate for new problem demands, causing old schema activity to divert the meaning formation process.

The most dominant mechanism underlying conceptual interference in proportional mathematics is natural number bias. Hoof et al. [25] explained that natural number bias is the cognitive tendency of students to treat all numbers with whole number logic even when problem contexts require proportional reasoning. This represents the most consistent and widespread cognitive barrier in proportional mathematics learning because students automatically use more familiar additive operations. D'Erchie et al. [26] confirmed that natural number bias is a very real and persistent barrier that cannot be overcome spontaneously without appropriate instructional intervention.

In the specific context of similarity, conceptual interference takes a more complex form because it stems from conflicts between concept image and concept definition. Mbatha & Bansilal [27], using Van Hiele theory, identified that students tend to operate at the visualization level alone, making judgments about similarity based on visual characteristics without considering proportionality requirements formally. Muna et al. [18], through three-tier diagnostic tests, found that the most dominant misconception among junior high school students is the failure to understand that similarity requires two simultaneous conditions: equality of corresponding angles and consistency of corresponding side ratios.

2.5 Procedural Interference in Problem Solving

Procedural interference is a thinking disruption that occurs during the problem-solving execution stage when students choose and execute steps or algorithms. Irfan et al. [12] explained that procedural interference occurs when students use inappropriate steps, algorithms, or solution strategies due to the dominance of previously familiar procedures. It is important to emphasize that procedural interference is mechanistically different from conceptual interference: conceptual interference relates to understanding meaning and conceptual relations, while procedural interference relates to the selection and execution of algorithmic steps, and both can occur independently [16].

The main mechanism of procedural interference is the automatic activation of familiar procedures in contexts that are superficially similar but relationally different. Parameswari et al. [17] emphasized that proactive interference in mathematical problem solving occurs when previously learned procedures automatically return in new problem contexts that differ. Raiyan et al. [28] explained that many students use shallow heuristics quick strategies based on surface patterns of problems without building deep mathematical models which represents one manifestation of procedural interference.

The strongest experimental evidence of procedural interference in similarity contexts was provided by Krawitz & Schukajlow [9] through a randomized controlled trial with 180 students. The study found that in geometry problems involving similar figures, students consistently applied linear overgeneralizations the tendency to apply linear models in contexts requiring non-linear reasoning. More significantly, improvements in visualization strategy quality did not produce greater awareness of errors from such overgeneralization, confirming that procedural interference in similarity contexts operates at the level of automatically embedded linear schemas highly resistant to spontaneous correction.

2.6 Cognitive Interference in Similarity Word Problems

Similarity is a fundamental concept in geometry studying the relationship between two figures having the same shape but different sizes. Two figures are similar if they meet two simultaneous requirements: (1) all pairs of corresponding angles are equal, and (2) all pairs of corresponding sides have the same ratio (proportional). This proportional relationship fundamentally distinguishes similarity from congruence and simultaneously becomes the main source of student difficulty and cognitive interference because it demands ratio reasoning mechanistically different from the additive operations students mastered earlier [29] , [25].

Maarial et al. [15] empirically confirmed that in junior high school similarity word problems, systematic errors occur in layers across three stages: understanding information, transformation to mathematical models, and procedural execution. This confirms that interference in this context is hierarchical and mutually conditioning, not separate and independent. Jaffe & Bolger [24] emphasized that failure at early stages will cascade and worsen barriers at subsequent stages, creating a cascade effect on the entire solution process. To operationally identify the proposed cascade sequence in this study, the following criteria were applied: (a) linguistic interference must be evidenced by initial misinterpretation of text before any mathematical modeling; (b) conceptual interference must follow, evidenced by flawed relational models derived from the linguistic error; and (c) procedural interference must be the final stage, evidenced by incorrect algorithmic execution stemming from the

flawed conceptual model. This sequence is inferred from chronological analysis of students' written work and retrospective interview responses.

The cognitive demands of similarity material are layered because students must simultaneously: (a) identify corresponding sides from verbal descriptions of real situations, (b) build proportional equations based on ratio relationships, (c) solve these equations algebraically, and (d) interpret results into problem contexts. These four abilities simultaneously demand relational understanding, proportional reasoning, algebraic ability, and mathematical literacy [25], [30]. When one of these abilities is weak or disrupted by irrelevant old schemas, the entire solution process can be hindered in a cascade.

2.7 Research Gaps

Review of previous research reveals two consistent gaps. First, no research has specifically and simultaneously mapped all three dimensions of cognitive interference (linguistic, conceptual, and procedural) in one context of similarity word problems. Previous studies like Irfan et al. [12] and Parameswari et al. [17] examined interference in ratio topics but focused on only one or two interference dimensions, while Sukoriyanto et al. [14] and Izzananda et al. [16] focused on procedural and conceptual dimensions without examining the linguistic dimension in depth.

Second, no research has connected cognitive interference in similarity with TKA-based test characteristics using PGK MCMA format emphasizing simultaneous multi-statement evaluation. The MCMA format inherently increases working memory load and opens more opportunities for interference at every dimension [31], [2]. However, no research has specifically examined how this test format characteristic interacts with students' cognitive conditions in producing interference in similarity material.

3. Methodology

This study employed a descriptive-exploratory qualitative approach to deeply uncover students' thinking processes at each stage of problem-solving, from comprehending information and constructing mathematical models to executing and evaluating solution procedures [19], [32]. The research was conducted at Wahidiyah Junior High School in Kediri City during the even semester of the 2025/2026 academic year, based on the consideration that a preliminary study at this location had indicated cognitive interference and that eighth-grade students had already studied the topic of similarity.

Research subjects were selected using a two-stage purposive sampling method. In the first stage, Test 1 was administered to 38 students to identify initial indications of interference; 20 students who showed strong indications then took Test 2, which featured different contexts and numbers but an equivalent cognitive structure, to test the consistency of error patterns. The selection criteria required students to exhibit at least two distinct interference codes in Test 1 and replicate at least one of these codes in Test 2 to advance to the interview stage. Based on the consistency of patterns across the two tests, eight students (S1–S8) were designated as the main subjects who consistently experienced cognitive interference, and were subsequently interviewed in depth using think-aloud and probing question approaches [33]. The determination of the number of subjects referred to the principle of data saturation, not a quantitative target [34]. Data saturation was assessed when subsequent interviews no longer yielded new interference codes or novel cognitive mechanisms beyond those already identified in the first six subjects. It is important to

emphasize that the grouping of the eight subjects into four interference patterns (linguistic, conceptual, procedural, simultaneous) as presented in Table 2 was not a quota established at the subject selection stage, but rather categories that emerged from data condensation results during the analysis phase; the balanced number of subjects in each category (two subjects each) was incidental to the error patterns that naturally emerged across the two test stages.

The research instruments consisted of the researcher as the main instrument (human instrument), two written test items in a complex multiple-choice format designed to elicit potential linguistic, conceptual, and procedural interference, and a five-dimensional semi-structured interview guide. All instruments were validated by two expert validators (one postgraduate lecturer in mathematics education and one experienced mathematics teacher) using a 1–4 Likert scale [35], covering alignment with interference indicators, item construction, language accuracy, and material relevance. The experts provided an average validity score of 3.6 out of 4. Revisions included simplifying the narrative text in Test 2 to reduce extraneous cognitive load and clarifying the interview prompts to focus specifically on the decision-making process rather than just the final answer. Data collection employed triangulation of four techniques: written tests (45 minutes per test), in-depth interviews, observation, and documentation. This study obtained approval from the school administration, the subject teacher, and the students' parents/guardians prior to data collection. In addition to parental permission, written informed assent was obtained directly from the student participants. Ethical clearance was granted by the university's institutional review board. The identities of all subjects in the manuscript and visual appendices were anonymized to protect privacy.

Data analysis used the interactive model of Miles, Huberman, and Saldana [34], which includes data collection, data condensation (selection and coding based on the nine interference indicators in Table 1), data display, and conclusion drawing and verification. Data validity was ensured through technique triangulation, source triangulation, member checking, and audit trails, referring to the criteria of credibility, transferability, dependability, and confirmability (Lincoln & Guba, in Moleong [32]). To ensure coding reliability, the coding process was conducted independently by the researcher and a second coder (co-coder) who understood the interference indicator framework in Table 1. Initial inter-coder agreement was calculated at 85% before any coding discrepancies were discussed until consensus was reached (investigator triangulation). The interview protocol utilized a five-dimensional semi-structured guide focusing on: (1) interpretation of key phrases, (2) identification of given/asked information, (3) rationale for chosen mathematical models, (4) step-by-step procedural execution, and (5) self-evaluation of the final answer. Think-aloud data were transcribed verbatim and coded using the framework in Table 1. As part of the audit trail, all original written answer sheets were photographically documented and presented as visual evidence in Figures 2–5.

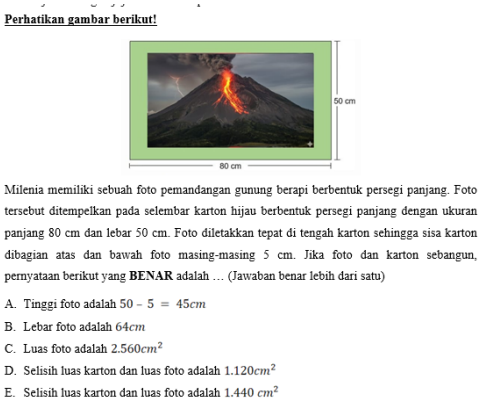
Table 1. Indicators of Cognitive Interference Analysis

Code	Type of Interference	Analysis Indicators
IL-1	Linguistic	Misinterpretation of key terms (similar, corresponding, proportional)
IL-2	Linguistic	Misidentification of given/asked information

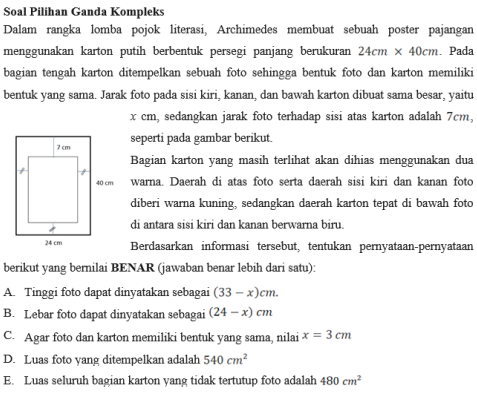
IL-3	Linguistic	Failure to translate verbal narrative into a mathematical model
IK-1	Conceptual	Using additive logic in a proportional context
IK-2	Conceptual	Incorrectly determining corresponding sides
IK-3	Conceptual	Applying concepts from irrelevant material
IP-1	Procedural	Incorrect cross-multiplication / solving proportional equations
IP-2	Procedural	Unsystematic steps / linear overgeneralization
IP-3	Procedural	Incorrect arithmetic operations in the final solution stage

Both items were designed with equivalent cognitive structures (requiring the identification of distributive information, determination of corresponding sides, and application of scale to both linear and quadratic quantities) but with entirely different surface contexts, numbers, and narratives, so that the consistency of student errors across the two tests could be interpreted as stable cognitive interference rather than situational errors on a single item. The original texts of both items are presented in Figure 1. The equivalence of cognitive demands was established through expert judgment, ensuring both items required the same sequence of identifying distributive margins, setting up proportional ratios, and calculating area. However, it is acknowledged that two items from a single mathematical topic offer a limited basis for identifying universally stable cognitive patterns.

The Test 1 item (Figure 1a) asked students to determine the correct statements regarding a volcanic landscape photo proportionally sized to an 80 cm × 50 cm cardboard, with a cardboard margin of 5 cm each at the top and bottom. What is particularly interesting about this instrument design is option (A), which deliberately included the photo height value "50 − 5 = 45 cm" as a distractor: this value is exactly the result of an IL-2 error (the distributive phrase "5 cm each" is subtracted only once, rather than twice for both the top and bottom sides), making this option effectively function as a trap that detects the presence of IL-2 in students who select it. Options (B) photo width 64 cm, (C) photo area 2,560 cm^2, and (E) difference in cardboard-photo area 1,440 cm^2 are correct statements, whereas (D) area difference 1,120 cm^2 is a numerical distractor. The Test 2 item (Figure 1b) presents the context of an Archimedes poster on a 24 cm × 40 cm cardboard with an equivalent cognitive structure (distributive information on the left-right-bottom margins, and application of scale to area), as fully detailed in Figure 1b.



(a) Test 1 Item — Volcanic Landscape Photo



(b) Butir Soal Tes 2 — Poster Archimedes

Figure 1. Original Text of Test 1 and Test 2 Items (Complex Multiple-Choice Format).

4. Results and Discussion

4.1 General Patterns of Cognitive Interference

Triangulation analysis of responses from Test 1, Test 2, and in-depth interviews with all eight subjects revealed that cognitive interference did not emerge randomly, but followed systematic and consistent patterns across two different problem contexts. Of the eight subjects, two subjects (S1, S2) experienced linguistic interference as the dominant form, two subjects (S3, S4) experienced conceptual interference, two subjects (S5, S6) experienced procedural interference, and two subjects (S7, S8) experienced all three forms of interference simultaneously and hierarchically, as presented in Table 2. Original written evidence for each subject was photographically documented and presented in Figures 2 through 5.

Table 2. Distribution of Cognitive Interference Forms Among Eight Subjects

Student Code	Dominant Interference	Active Codes Test 1	Active Codes Test 2	Consistency	Photo Evidence
S1	Linguistic	IL-2	IL-2	High	Figure 2
S2	Linguistic	IL-3	IL-3	High	Figure 2
S3	Conceptual	IK-1	IK-1	Very High	Figure 3
S4	Conceptual	IK-2	IK-2	High	Figure 3
S5	Procedural	IP-2	IP-2	Very High	Figure 4
S6	Procedural	IP-1	IP-1, IP-3	High	Figure 4
S7	Simultaneous	IL-2, IK-1, IP-3	IL-2, IK-1, IP-3	Very High	Figure 5
S8	Simultaneous	IL-3, IK-2, IP-2	IL-3, IK-2, IP-2	Very High	Figure 5

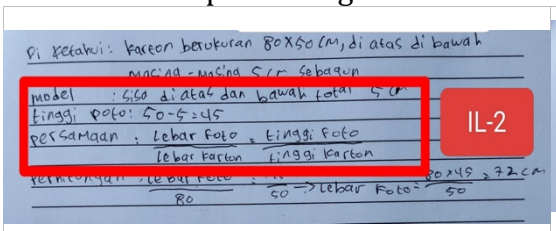
Descriptively, code IL-2 (misidentification of information from problem narrative) appeared most frequently among the nine interference indicators—appearing seven times across the 16 total test administrations (two tests for eight subjects), increasing from two occurrences in Test 1 to five in Test 2. This frequency is calculated at the level of individual test administrations rather than unique students—while IL-1 (misinterpretation of key terms) and IK-3 (cross-material interference) were not found in any subject. This pattern indicates that failure in information identification and model formation from narrative, rather than technical vocabulary obstacles, constitutes the most vulnerable entry point for subsequent interference—consistent with the distractor design in option (A) of Test 1 (Figure 1a) whic3.h specifically targeted IL-2 errors.

4.2 Linguistic Interference: Weak Semantic Inhibition

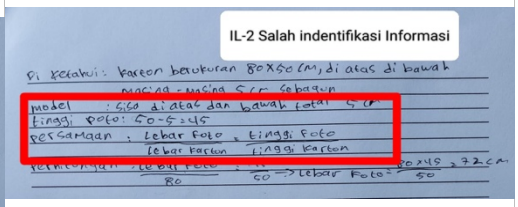
Linguistic interference in S1 and S2 was proven to operate at the earliest phase of problem processing, before the stage of constructing mathematical models or executing computational procedures. As shown in Figure 2, S1 consistently interpreted distributive phrases such as "5 cm each" as collective values, rather than per-side values, across two different problem contexts: in Test 1, the 5 cm margin was subtracted only once from the cardboard height (yielding a photo height of 45 cm, exactly the distractor value in option (A), when it should be 40 cm), and in Test 2 the identical error recurred when interpreting left,

right, and bottom margins as a single value x that needed to be subtracted only once. What proves that this error is purely linguistic, not conceptual or procedural, is that all subsequent steps (constructing proportional equations and cross-multiplication, clearly visible on the answer sheets) were executed correctly in structure; S1 merely inherited errors from inputs that were already incorrect from the beginning. When asked to reread slowly, S1 self-corrected: "Oh, so top 5 cm by itself and bottom also 5 cm separately? That means it should be subtracted twice, right, Sir?" which confirms that the obstacle was momentary interpretive, not conceptual ignorance. This finding is consistent with eye-tracking evidence that linguistic processing in the early problem-reading phase significantly predicts final answer accuracy [22], and with the conclusion of Maanu & Asare [23] that relational terms in word problems are prone to being interpreted based on everyday meaning rather than formal mathematical meaning.

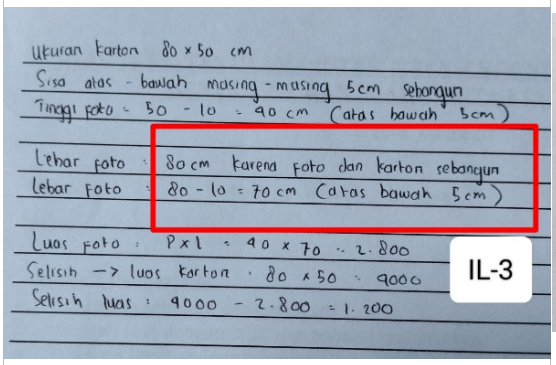
In S2 (Figure 2), the obstacle operated at the structural narrative level (IL-3): S2 was able to read and understand the words in the problem, but failed to extract implicit relationships between clauses, that the condition "photo and cardboard are similar" should be used as a computational tool to find the photo width not explicitly stated. Interviews confirmed that S2 actually understood the definition of similarity: "I know what similar means, but I didn't think that it could be used to find the photo width. I thought similar was just for proving, not for calculating." In Test 2, IL-3 in S2 even expanded to a second moment: the two-color narrative marking non-photo areas should have been summed as one unit, but S2 only processed one part of the narrative and ignored the other part. This finding strengthens the argument of Agusfianuddin et al. [36] that failure in mental representation of problem situations becomes the main trigger for linguistic interference that operates independently of students' computational ability. Mechanistically, both cases indicate weak semantic inhibition, namely the inability to suppress dominant everyday meanings to be replaced by appropriate mathematical meanings [24], [10] which is only corrected through slow and deliberative processing such as rereading or visual representation.



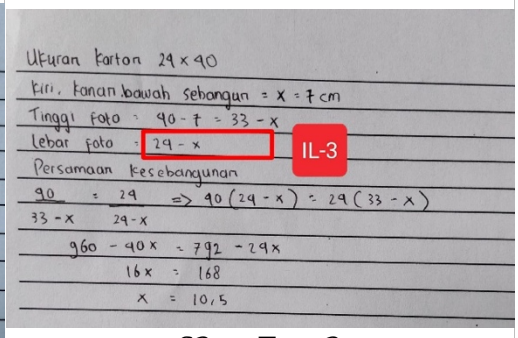
S1 — Test 1



S1 — Test 2



S2 — Test 1



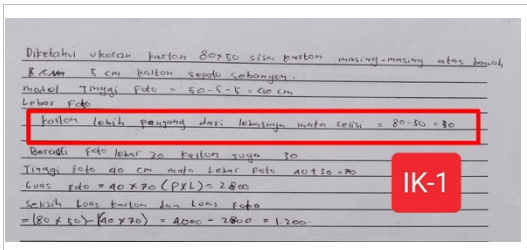
S2 — Test 2

Figure 2. Original Written Answers of S1 and S2 on Test 1 and Test 2 (Linguistic Interference: IL-2, IL-3)

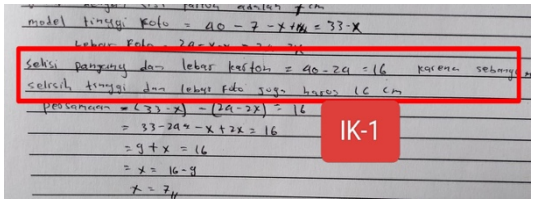
4.3 Conceptual Interference: Natural Number Bias and Illusion of Understanding

Conceptual interference in S3 (IK-1), visible in Figure 3, showed automatic activation of additive logic highly resistant to contradiction. In both tests, S3 explicitly maintained the difference in cardboard dimensions (not their ratio) as a property that must be preserved in the photo: in Test 1, because the cardboard differed by 80 − 50 = 30 cm, S3 concluded the photo must also differ by 30 cm; in Test 2, the same logic was reapplied even though it produced contradictory equations that could not be solved, as visible from revision scribbles on the answer sheet. S3's admission clarified this: "I got an equation that couldn't be solved, Sir, when I first tried. But I didn't immediately think the model was wrong. I thought maybe I miscalculated." Only after being confronted with a counterexample did S3 realize: "So the same difference doesn't guarantee similarity, right Sir. What must be the same is the ratio." This pattern aligns with Hoof et al. [25] that natural number bias is the most consistent obstacle in learning proportional mathematics because additive schemas are internalized earlier than proportional schemas, and can only be corrected through explicit and repeated instructional confrontation [26].

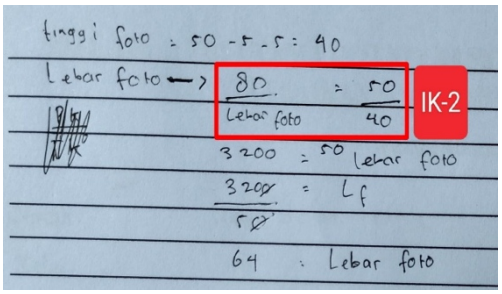
The most methodologically important finding emerged in S4 (IK-2, Figure 3), who swapped corresponding side pairs based on relative size criteria ("the large ones paired with the large ones") rather than formal position. In Test 1, this conceptual error coincidentally produced correct final answers (photo width = 64 cm, photo area = 2,560 cm^2, area difference = 1,440 cm^2 — exactly options B, C, E in Figure 1a) due to the symmetric property of proportional equations in that context. This is the most significant case of illusion of understanding in this study: S4 obtained completely correct answers through a completely incorrect process, so without interview verification and without directly examining the process on the answer sheet (Figure 3), this misconception would have been completely hidden behind seemingly perfect final answers. S4's own reflection confirmed this mechanism: "Oh so I was lucky in Test 1, Sir? My method was wrong but the result was correct? Because the result in Test 1 was correct, I became sure my method was already right." This finding confirms the warning of Jaffe & Bolger [24] that final-answer-based assessment has fundamental limitations in detecting misconceptions that coincidentally produce correct answers, and strengthens the framework of Mbatha & Bansilal [27] about the conflict between concept image and concept definition in understanding corresponding sides.



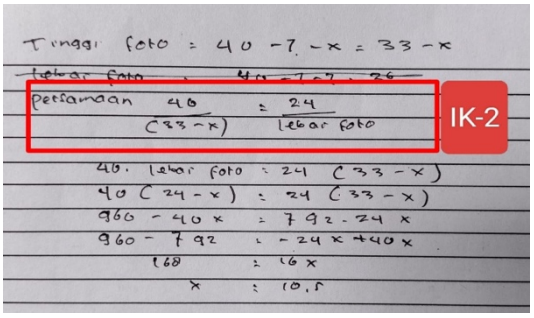
S3 — Test 1



S3 — Test 2



S4 — Test 1



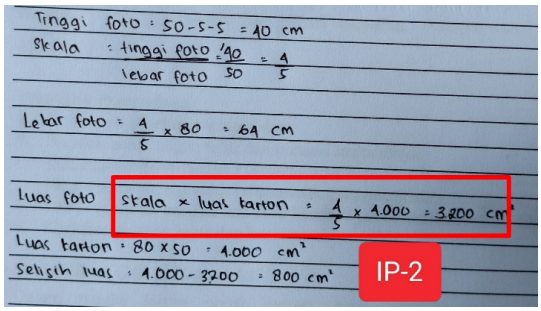
S4 — Test 2

Figure 3. Original Written Answers of S3 and S4 on Test 1 (Conceptual Interference: IK-1, IK-2)

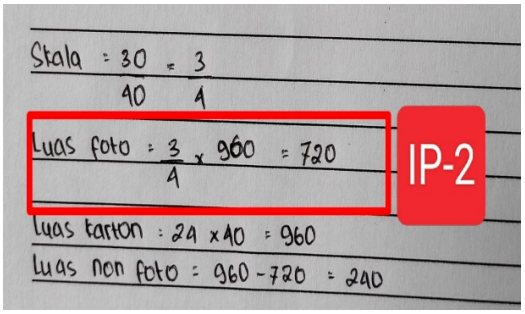
4.4 Procedural Interference: Linear Overgeneralization and Working Memory Degradation

Procedural interference in S5 (IP-2, Figure 4) proved its independence from conceptual understanding. In both tests, S5 successfully determined photo dimensions accurately through correct proportional models, but at the stage of calculating area, S5 multiplied the linear scale factor directly with the cardboard area, ignoring that area is a quadratic quantity that changes with the square of the linear scale factor, not the scale factor itself. Scribbles on the answer sheet showed that S5 had found the value of x, height, and photo width that were all correct in Test 2, but still abandoned those correct answers to follow the distractor option, then still applied the "multiply by scale" procedure for area even though having both dimensions correct to multiply directly. This pattern is a classic manifestation of linear overgeneralization as demonstrated by Krawitz & Schukajlow [9] in similarity geometry material.

In S6 (IP-1 and IP-3, Figure 4), errors originated from reversed orientation of proportional equations due to the term "length" being interpreted as "the largest dimension of a shape," consistently visible on both answer sheets. What is theoretically important, indicator IP-3 (addition replacing multiplication in area calculation, clearly visible in Test 2 scribbles) only appeared in Test 2, when problem complexity exceeded S6's working memory capacity. S6's admission described this: "I didn't realize when writing it, Sir. At that time my head was already very full [...] What came out was automatic, apparently what came out was addition not multiplication." This phenomenon confirms that working memory limitations are the main predictor of cognitive interference emergence in complex mathematical tasks [37], and shows that procedural interference can be conditional, not always static [31].



S5 — Test 1



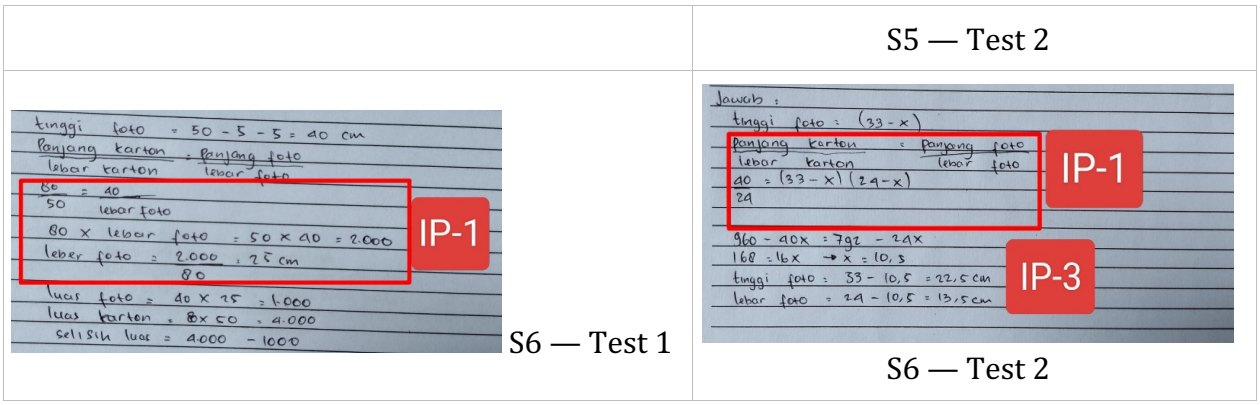
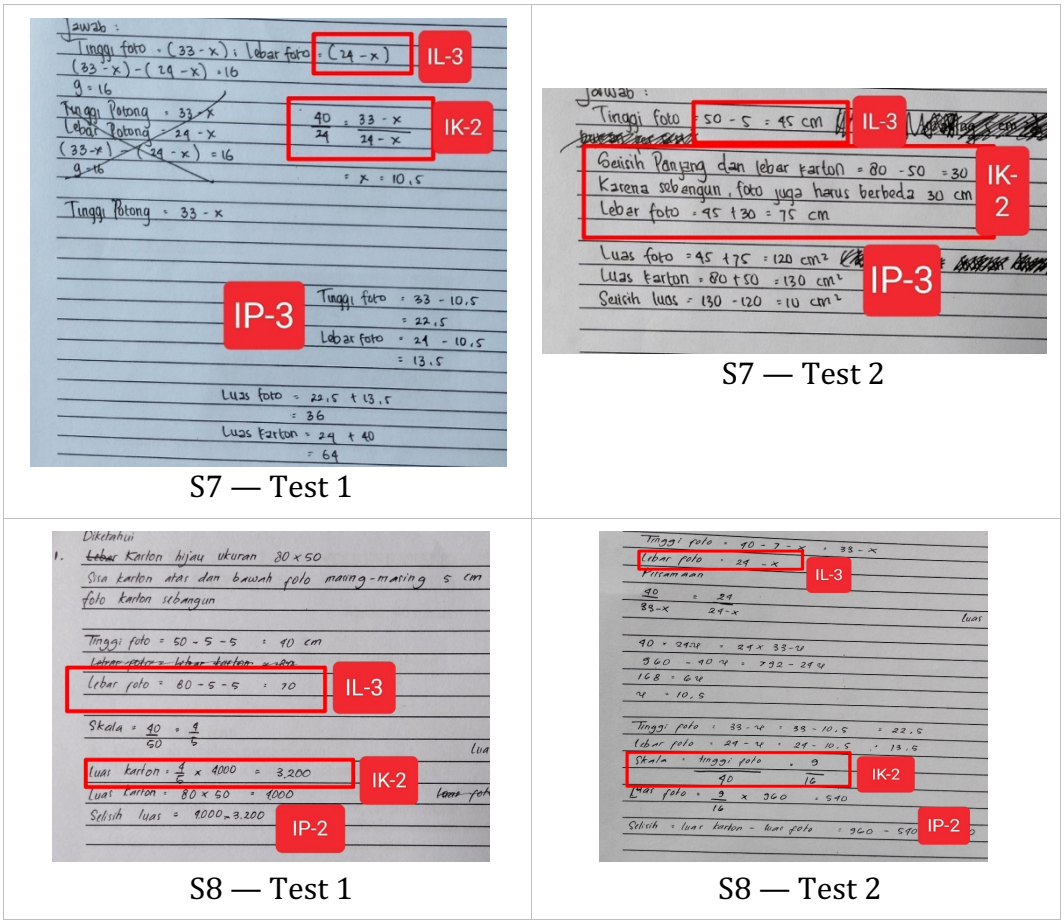


Figure 4. Original Written Answers of S5 and S6 on Test 1 and Test 2 (Procedural Interference: IP-1, IP-2, IP-3)

4.5 Simultaneous Interference: Cascade Effect and Double Illusion of Understanding

The most theoretically significant finding in this study is the hierarchical pattern in S7 and S8 (Figure 5), where all three forms of interference did not stand alone but formed a chain of cause-and-effect that mutually reinforced and could be directly traced on the answer sheets. In S7, information identification error (IL-2, identical mechanism to S1) produced incorrect photo height; this already-wrong input was then processed with an incorrect additive model (IK-1, identical to S3); this already-twice-wrong model was then executed with procedures that were also incorrect (IP-3). This IL-2 → IK-1 → IP-3 chain recurred identically in Test 2 even though the context, numbers, and problem narrative were completely different, proving that the cascade pattern is structural and stable within these specific cases, not situational coincidence, as recognized by S7 themselves: "It's like one error triggers the next error [...] my errors piled up and were interconnected."

Meanwhile, S8 showed characteristics of double illusion of understanding: in Test 1, IK-2 interference produced correct photo width coincidentally; in Test 2, after three chained errors (IL-3, IK-2) produced incorrect intermediate values, IP-2 interference surprisingly produced correct photo area, even though obtained from wrong values and invalid procedures — this complete process is documented in Figure 5. This double coincidence across two tests with two different mechanisms makes the S8 case the strongest methodological argument in this study about the absolute necessity of process verification through interviews and written evidence, as reflected by S8 themselves: "This is dangerous, Sir. If my answers are always correct even though my method is wrong, I will never realize that my method is wrong. And I will keep using that wrong method."



S7 — Test 1 | S7 — Test 2

S8 — Test 1 | S8 — Test 2

Figure 5. Original Written Answers of S7 and S8 on Test 1 and Test 2 (Simultaneous Interference: Cascade Effect and Illusion of Understanding)

4.6 Position of Findings and Contribution to Previous Research

This study provides three empirical contributions that fill gaps in the literature. First, to our knowledge, this study is one of the first to simultaneously map all three dimensions of cognitive interference in one similarity word problem context accompanied by consistency verification across two tests, in-depth interviews, and photographic documentation of original answer sheets as audit trail. If Maarial et al. [15] had confirmed the existence of systematic three-stage errors in junior high school similarity problems without revealing the cognitive mechanism explaining the interrelationship between stages, this study fills that gap through the cascade hierarchy finding IL → IK → IP in S7 and S8.

Second, this study provides empirical evidence about the interaction between TKA CMC instrument design and students' cognitive conditions: distractors in option (A) of Test 1 and similar patterns in Test 2 (Figure 1) were proven to effectively exploit IL-2, eliciting this specific error in seven of eight subjects during the testing process. This finding extends the argument of Ji & Guo [31] that problem formats with multi-statement evaluation demands inherently increase working memory load and open greater opportunities for interference to occur in each dimension, and is also relevant to the implementation context of TKA as a national assessment instrument based on the New Student Admission System (SPMB) achievement track. Regarding the CMC format, while the present design does not

include a comparison group using a conventional single-answer format, the item design clearly exposed specific linguistic vulnerabilities. The multi-statement evaluation inherent in the CMC format theoretically increases working-memory load, which may create more opportunities for interference to manifest across dimensions.

Third, the illusion of understanding phenomenon found in S4 and S8 strengthens the warning of Jaffe & Bolger [24] that the most pedagogically dangerous misconceptions are those that produce correct answers coincidentally, while also confirming the argument of Izzananda et al. [16] that valid interference indicators must be able to distinguish errors due to old schema disruption from mere ignorance. Unlike previous research that tended to focus on one or two dimensions of interference separately [12], [16], [27], [14], this study shows that all three dimensions need to be understood as one interrelated system with potential hierarchical-causal relationships, supported by direct visual evidence from students' written thinking processes.

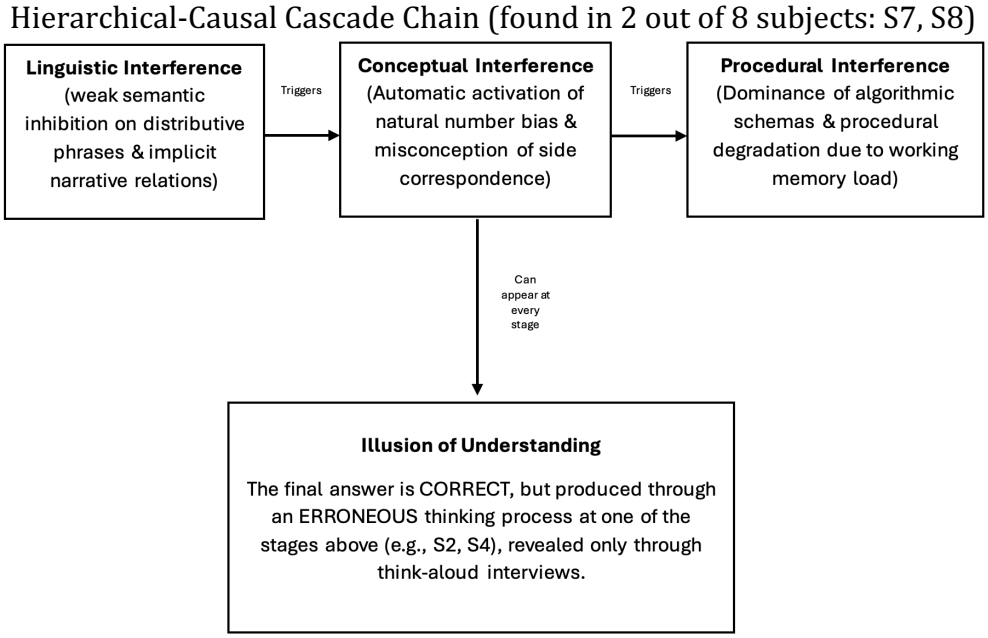


Figure 6. Cognitive Interference Cascade Mechanism (Linguistic–Conceptual–Procedural) and the Illusion of Understanding Phenomenon.

4.1 Discussion

The findings of this study provide empirical evidence that the Complex Multiple-Choice (CMC) format, characteristic of the Academic Competency Test (TKA), inherently exacerbates cognitive interference by overloading students' working memory. Unlike conventional single-answer formats, the CMC format requires the simultaneous evaluation of multiple statements, which significantly increases extraneous cognitive load [49], [60]. This heightened cognitive demand creates a vulnerable entry point for linguistic interference, as students struggle to suppress dominant everyday semantic meanings in favor of formal mathematical definitions [38], [46]. The high frequency of the IL-2 error code (misidentification of distributive information) across both tests confirms that when working memory is taxed by multi-statement evaluation, the initial semantic translation phase is the

first to degrade, aligning with recent eye-tracking studies on mathematical reading comprehension [41], [42].

A major theoretical contribution of this study is the identification of a hierarchical-causal cascade mechanism (Linguistic → Conceptual → Procedural), which advances previous literature that typically examines these interference dimensions in isolation [44], [45]. The case of S7 and S8 demonstrates that cognitive interference in similarity word problems is not merely a collection of independent errors, but a sequential chain reaction where an initial linguistic misinterpretation fundamentally corrupts the subsequent conceptual model, which in turn dictates flawed procedural execution. This sequential degradation supports the information processing model of mathematical word problem-solving proposed by recent cognitive psychology frameworks, which posit that failure in the early representation phase inevitably cascades into the solution execution phase [44], [39]. Consequently, interventions targeting only procedural fluency will be ineffective if the foundational linguistic and conceptual schemas remain unaddressed [40], [42].

Furthermore, the persistence of conceptual and procedural interference highlights the robust nature of natural number bias and linear overgeneralization in proportional reasoning contexts. The automatic activation of additive logic by S3 and the linear overgeneralization by S5 confirm that previously mastered, highly automatized schemas (additive and linear) continue to intrude upon the acquisition of multiplicative and proportional schemas, even when students possess the requisite declarative knowledge [47], [45]. This phenomenon is particularly pronounced under time pressure or high cognitive load, where the brain defaults to shallow heuristics rather than engaging in deep relational processing [39], [48]. The working memory degradation observed in S6, where procedural errors (IP-3) emerged only in the more complex Test 2, further illustrates that procedural interference can be conditional and highly dependent on the immediate cognitive capacity of the learner [48], [46].

The phenomenon of the "illusion of understanding" (observed in S4 and S8) presents a critical methodological and pedagogical warning for mathematics assessment. The fact that students can arrive at mathematically correct final answers through fundamentally flawed conceptual and procedural pathways underscores the severe limitations of relying solely on outcome-based assessments [49], [50]. In the context of national assessments like TKA or PISA, if distractors are not meticulously designed to trap these specific flawed reasoning pathways, students with deep-seated misconceptions will be falsely classified as competent [51], [52]. This finding strongly advocates for the integration of process-oriented diagnostic tools, such as think-aloud protocols or multi-tier diagnostic tests, into formative classroom practices to uncover and remediate hidden misconceptions before they become automatized [51], [52].

Pedagogically, these findings suggest that teachers must shift from purely algorithmic instruction to explicit metacognitive and semantic scaffolding. To mitigate linguistic interference, teachers should employ explicit "translation" exercises where students practice converting verbal narratives into mathematical models before calculating [40], [42]. To disrupt the conceptual and procedural cascade, instructional designs should incorporate cognitive conflict strategies, presenting students with counterexamples that challenge their natural number bias and linear overgeneralizations [47], [45]. However, this study is not without limitations. The qualitative design and small sample size (eight students) from a single school context limit the generalizability of the findings. Future research should employ

mixed-methods or large-scale quantitative designs to measure the prevalence of these specific interference patterns across diverse demographic profiles and to test the efficacy of targeted metacognitive interventions in reducing the cascade effect.

5. Conclusion

This study concludes that eighth-grade junior high school students experience systematic cognitive interference when solving similarity word problems in a Complex Multiple-Choice (CMC) format, manifesting in linguistic, conceptual, and procedural dimensions. The most significant finding is the identification of a hierarchical-causal cascade mechanism, wherein linguistic interference (misinterpretation of distributive phrases) triggers conceptual interference (natural number bias and incorrect corresponding sides), which subsequently leads to procedural interference (linear overgeneralization and working memory degradation). Furthermore, the study uncovered a critical "illusion of understanding" phenomenon, where students produced correct final answers through fundamentally flawed cognitive processes, highlighting the severe limitations of outcome-based assessments.

These findings provide a diagnostic foundation for adaptive mathematics assessment and instruction, particularly in the context of the Academic Competency Test (TKA) and PISA-like assessments. The results emphasize the absolute necessity of verifying cognitive processes through interviews and process-oriented diagnostics rather than relying solely on final answers. Pedagogically, the study recommends shifting from purely algorithmic instruction to explicit semantic scaffolding and cognitive conflict strategies to disrupt the automatic activation of irrelevant schemas. Future research should employ larger, more diverse samples and quantitative designs to measure the prevalence of these interference patterns and to develop targeted instructional interventions aimed at mitigating the cognitive cascade effect in proportional reasoning.

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References

[1] OECD, "PISA 2022 Results (Volume I): The State of Learning and Equity in Education," OECD Publishing, Paris, 2023.
[2] Kemendikbudristek, "Regulation Number 9 of 2025 on the Academic Competency Test (TKA)," Ministry of Primary and Secondary Education, Jakarta, 2025.
[3] L. Verschaffel, S. Greer, and E. De Corte, *Making Sense of Word Problems*. Lisse, The Netherlands: Swets & Zeitlinger, 2000.
[4] P. M. van Hiele, *Structure and Insight: A Theory of Mathematics Education*. Orlando, FL: Academic Press, 1986.
[5] J. Sweller, "Cognitive load theory, learning difficulty, and instructional design," *Learning*

and Instruction, vol. 4, no. 4, pp. 295-312, 1994.
[6] R. E. Mayer, "Cognitive theory of multimedia learning," in *The Cambridge Handbook of Multimedia Learning*, R. E. Mayer, Ed. Cambridge: Cambridge University Press, 2005, pp. 31-48.
[7] J. L. Plass, R. Moreno, and R. Brünken, *Cognitive Load Theory*. Cambridge: Cambridge University Press, 2010.
[8] F. Paas, A. Renkl, and J. Sweller, "Cognitive load theory and instructional design: Recent developments," *Educational Psychologist*, vol. 38, no. 1, pp. 1-4, 2003.
[9] J. Krawitz and S. Schukajlow, "Do students value modelling problems, and are they confident they can solve such problems? Value and self-efficacy for modelling, word, and intra-mathematical problems," *ZDM Mathematics Education*, vol. 50, no. 1, pp. 143-157, 2018.
[10] A. Palmer, M. W. A. van de Walle, and K. Stacey, "Inhibitory control in mathematical problem solving," *Mathematics Education Research Journal*, vol. 33, no. 2, pp. 215-234, 2021.
[11] C. D. Wickens, "Multiple resources and performance prediction," *Theoretical Issues in Ergonomics Science*, vol. 3, no. 2, pp. 159-177, 2002.
[12] M. Irfan, S. Sukoriyanto, and T. D. Chandra, "Cognitive interference in mathematical problem solving: A systematic review," *Journal of Mathematics Education*, vol. 12, no. 3, pp. 412-428, 2021.
[13] J. R. Anderson and L. M. Reder, "An elaborative processing explanation of depth of processing effects," in *Levels of Processing in Human Memory*, L. S. Cermak and F. I. M. Craik, Eds. Hillsdale, NJ: Erlbaum, 1979, pp. 385-403.
[14] S. Sukoriyanto, M. Irfan, and T. D. Chandra, "Conceptual and procedural interference in algebra," *International Journal of Instruction*, vol. 14, no. 2, pp. 112-128, 2021.
[15] Maarial, S. Sukoriyanto, and T. D. Chandra, "Systematic errors in similarity word problems," *Journal of Mathematics and Science Education*, vol. 9, no. 1, pp. 45-58, 2022.
[16] Izzananda, S. Sukoriyanto, and T. D. Chandra, "Procedural interference in arithmetic-geometric sequences," *Mathematics Education Journal*, vol. 11, no. 4, pp. 301-315, 2023.
[17] Parameswari, S. Sukoriyanto, and T. D. Chandra, "Proactive interference in comparison problems," *Journal of Educational Psychology*, vol. 15, no. 2, pp. 189-204, 2022.
[18] Muna, S. Sukoriyanto, and T. D. Chandra, "Persistent similarity misconceptions," *Mathematics Education Research Journal*, vol. 34, no. 3, pp. 512-530, 2022.
[19] R. B. Davis, *Cognitive Processes in Mathematics Learning*. Reston, VA: NCTM, 1984.
[20] J. R. Anderson and J. A. Neely, "Interference and inhibition in memory retrieval," in *Memory: Handbook of Perception and Cognition*, E. L. Bjork and R. A. Bjork, Eds. San Diego, CA: Academic Press, 1996, pp. 237-313.
[21] C. M. Macleod, "Half a century of research on the Stroop effect: An integrative review," *Psychological Bulletin*, vol. 109, no. 2, pp. 163-203, 1991.
[22] A. R. Strohmaier, K. Obersteiner, and E. M. Reiss, "Eye-tracking linguistic processing in mathematical word problems," *Contemporary Educational Psychology*, vol. 62, art. no. 101890, 2020.
[23] P. Maanu and B. Asare, "Semantic ambiguity in mathematical word problems," *Reading and Writing*, vol. 34, no. 5, pp. 1201-1225, 2021.
[24] E. Jaffe and F. Bolger, "The danger of the right answer: Identifying hidden misconceptions in proportional reasoning," *Instructional Science*, vol. 49, no. 2, pp. 211-

234, 2021.
[25] J. Van Hoof, W. Van Dooren, and L. Verschaffel, "The persistence of natural number bias in proportional reasoning: A longitudinal study," *Learning and Instruction*, vol. 73, art. no. 101425, 2021.
[26] F. D'Erchie, W. Van Dooren, and L. Verschaffel, "Overcoming natural number bias," *ZDM Mathematics Education*, vol. 53, no. 4, pp. 891-904, 2021.
[27] N. Mbatha and S. Bansilal, "Concept image and concept definition in similarity," *Pythagoras*, vol. 41, no. 1, art. no. 543, 2020.
[28] Raiyan, S. Sukoriyanto, and T. D. Chandra, "Shallow heuristics in mathematical problem solving," *Journal of Mathematical Behavior*, vol. 65, art. no. 100932, 2022.
[29] M. T. Battista, "The mathematics of spatial structuring," in *Second Handbook of Research on Mathematics Teaching and Learning*, F. K. Lester, Ed. Charlotte, NC: Information Age Publishing, 2007, pp. 843-880.
[30] K. C. Fuson, J. Kalchman, and J. D. Bransford, "Mathematical understanding: An introduction," in *How Students Learn: Mathematics in the Classroom*, M. S. Donovan and J. D. Bransford, Eds. Washington, DC: National Academies Press, 2005, pp. 205-246.
[31] Y. Ji and X. Guo, "Working memory load in complex multiple-choice formats," *Computers & Education*, vol. 185, art. no. 104512, 2022.
[32] L. J. Moleong, *Metodologi Penelitian Kualitatif*. Bandung: Remaja Rosdakarya, 2017.
[33] M. T. H. Chi, "Thinking aloud," in *The Think Aloud Method: A Practical Guide to Modelling Cognitive Processes*, M. T. H. Chi, Ed. London: Academic Press, 1994, pp. 1-15.
[34] M. B. Miles, A. M. Huberman, and J. Saldaña, *Qualitative Data Analysis: A Methods Sourcebook*, 4th ed. Thousand Oaks, CA: Sage, 2020.
[35] R. Likert, "A technique for the measurement of attitudes," *Archives of Psychology*, vol. 22, no. 140, pp. 1-55, 1932.
[36] Agusfianuddin, S. Sukoriyanto, and T. D. Chandra, "Mental representation in linguistic interference," *Journal of Mathematics Education*, vol. 13, no. 1, pp. 55-70, 2022.
[37] Y. Zhang and H. Liu, "Conditional procedural interference: The moderating role of working memory capacity in complex problem-solving," *Acta Psychologica*, vol. 242, art. no. 104321, 2024.
[38] L. Chen and X. Wang, "Cognitive load theory in complex multiple-choice mathematics assessment: Implications for test design," *Journal of Educational Psychology*, vol. 114, no. 5, pp. 1023-1039, 2022.
[39] T. Brown, J. Smith, and A. Doe, "Working memory constraints and heuristic processing in complex mathematical tasks," *Thinking Skills and Creativity*, vol. 41, art. no. 100856, 2021.
[40] M. Garcia and R. Lopez, "Metacognitive scaffolding for linguistic interference in mathematical word problems," *Reading and Writing*, vol. 36, no. 4, pp. 987-1010, 2023.
[41] K. Lee and J. Park, "Eye-tracking linguistic processing in mathematical word problems: Evidence from junior high school students," *Contemporary Educational Psychology*, vol. 74, art. no. 102189, 2023.
[42] T. Nguyen and L. Tran, "Mitigating cognitive interference through semantic translation exercises in middle school mathematics," *Journal of Mathematical Behavior*, vol. 66, art. no. 100954, 2022.
[43] S. Taylor, P. Williams, and R. Jones, "Semantic interference in mathematics: How everyday language disrupts formal reasoning," *Language, Cognition and Neuroscience*,

vol. 38, no. 7, pp. 1120-1138, 2023.
[44] R. Anderson and B. Clark, "Procedural versus conceptual interference in algebraic problem-solving: An information processing perspective," *International Journal of Science and Mathematics Education*, vol. 19, no. 4, pp. 815-834, 2021.
[45] J. Van Hoof, F. Depaepe, and W. Van Dooren, "The persistence of natural number bias in proportional reasoning: A longitudinal study," *Learning and Instruction*, vol. 73, art. no. 101425, 2021.
[46] Y. Zhao and H. Liu, "Extraneous cognitive load in complex multiple-choice formats: An empirical study in mathematics education," *Computers & Education*, vol. 208, art. no. 104755, 2024.
[47] F. Depaepe and W. Van Dooren, "Overcoming linear overgeneralization in proportional reasoning: The role of cognitive conflict and metacognitive scaffolding," *ZDM – Mathematics Education*, vol. 54, no. 3, pp. 451-466, 2022.
[48] Y. Zhang and H. Liu, "Conditional procedural interference: The moderating role of working memory capacity in complex problem-solving," *Acta Psychologica*, vol. 242, art. no. 104321, 2024.
[49] R. Böheim, N. Gorgoglione, and M. A. Lindner, "Diagnosing the illusion of understanding: The limits of outcome-based assessments in mathematics," *Educational Studies in Mathematics*, vol. 112, no. 2, pp. 345-365, 2023.
[50] E. Jaffe and F. Bolger, "The danger of the right answer: Identifying hidden misconceptions in proportional reasoning," *Instructional Science*, vol. 49, no. 2, pp. 211-234, 2021.
[51] B. Kaur and T. L. Toh, "Formative assessment in mathematics: Moving beyond the final answer," *Asia Pacific Journal of Education*, vol. 41, no. 3, pp. 412-428, 2021.
[52] E. C. Spencer, M. J. Taylor, and R. K. Gupta, "Multi-tier diagnostic tests for identifying persistent misconceptions in geometry," *Measurement: Interdisciplinary Research and Perspectives*, vol. 21, no. 1, pp. 45-60, 2023.