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Examining Obstacles in Representing the Fraction Part-whole Subconstruct: A Study of Junior High School Students in South Sulawesi, Indonesia

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Abstract

Understanding the part-whole fraction subconstruct is essential for developing mathematical literacy, yet many students still struggle to coordinate fraction meanings across visual, symbolic and contextual representations. This study examined how epistemological, ontogenic and didactical obstacles interact in students' representation of part-whole fractions within Brousseau's Theory of Didactic Situations. An exploratory case study design was used, involving 187 Grade 7 students and 12 mathematics teachers from 12 schools in South Sulawesi, Indonesia. Data were collected through diagnostic tests, classroom observations and clinical interviews. Quantitative test data were analyzed using descriptive statistics and classroom-level comparisons, while qualitative data were analyzed through theory-driven coding and triangulation across data sources. The findings showed that 56.7% of students experienced epistemological obstacles, especially natural number bias, while 62.6% showed ontogenic obstacles related to developmental limitations in coordinating equal parts and whole-unit relationships. Didactical obstacles were identified in 91.7% of classroom teaching practices, mainly through representational monotony and premature institutionalization. Triangulation revealed four interaction mechanisms: representational monotony amplified context-bound understanding, didactic contract norms sustained natural number bias, premature division terminology triggered symbolic interference and limited action situations hindered the development of equipartitioning. This study contributes a systemic model explaining how milieu design, didactic contract norms and institutionalization timing shape persistent fraction errors, thereby shifting the focus from individual student deficits to didactic system redesign.

Keywords: Didactic Contract, Fraction Representation, Learning Obstacles, Natural Number Bias, Part-whole Fractions, Theory of Didactic Situations.

Introduction

Understanding the part-whole subconstruct of fractions is a key component of mathematical literacy and supports later learning in algebra, calculus and other abstract mathematics (1, 2). In the 2018 Programme for International Student Assessment (PISA) results, 71% of Indonesian students performed at Level 1 or below in mathematics, indicating limited proficiency in using mathematics to solve problems in varied contexts (3). This condition highlights the need for a fine-grained analysis of students' mathematical difficulties, particularly in foundational topics such as fractions, where representational coordination is essential. Recent work treats fraction difficulty as multidimensional rather than as an isolated student deficit (4). Fractions involve several interconnected subconstructs and teaching must coordinate meanings and representations to avoid fragmented understanding (5). Ontogenic obstacles relate to readiness, spatial reasoning and conceptual abstraction (6). Epistemological obstacles arise when previously productive knowledge becomes resistant in a new domain, for example when whole-number reasoning interferes with fraction reasoning (7, 8). Didactical obstacles arise from classroom practices, including task design, representation choices, feedback and implicit norms (9). These categories can co-occur and interact, which helps explain why fraction difficulties remain persistent and can extend into higher education (10, 11). The part-whole subconstruct provides a focused entry point because it forms a foundational meaning of fractions. Although fraction knowledge includes measure, quotient, ratio and operator meanings, the part-whole subconstruct was selected because

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was selected because it is commonly introduced early in school mathematics and directly involves equal partitioning, whole-unit reference, numerator-denominator coordination and representational translation (5, 12). A fraction expresses a relationship between equal parts and a whole unit partitioned into equal segments (9, 12). To construct this meaning, students must identify the referent whole, perform equipartitioning and coordinate numerator and denominator as one relational quantity (13, 14). Part-whole understanding is also representational. Students encounter fractions through area models, set models, number lines, symbolic notation and verbal expressions (15, 16). Conceptual depth depends on the ability to interpret, translate and justify across these representations (17).

From the perspective of didactics of mathematics, learning obstacles can be described as ontogenic, epistemological and didactical (18). Ontogenic obstacles appear when students cannot stabilise prerequisite structures needed to enter a task meaningfully. In part-whole fractions, these obstacles include non-equivalent partitioning, unstable identification of the whole and weak conservation of the whole across shapes or contexts (4, 19). Students may also struggle to decontextualise part-whole meaning beyond familiar models, which limits transfer to new tasks and representations (20).

Epistemological obstacles appear when stable prior reasoning resists change. In fraction learning, a central case is whole-number bias, also referred to as natural number bias, in which students overgeneralise whole-number properties to fractions and treat the numerator and denominator as independent whole numbers (21). This bias appears in patterns such as denominator-based comparisons, component-wise operations and magnitude misunderstandings that persist across tasks and representations (22). Epistemological obstacles are not simply isolated misconceptions. They reflect robust reasoning that students have used successfully in earlier mathematical contexts and therefore apply again, even when inappropriate (8, 18, 23).

Didactical obstacles appear when instruction constrains the learning milieu through limited models, narrow task variation, or representational privileging. Over-reliance on a single representation can produce model bias and restrict students' opportunities to coordinate meanings across representations (24). Instruction can also over-stabilise routines and shift attention away from unit definition, equivalence and numerator-denominator coordination, which narrows fraction meaning and weakens transfer (25). Conceptual development improves when instruction integrates multiple representations and requires students to explain and justify their reasoning (26).

Despite this knowledge base, gaps remain. First, many studies rely on experimental or survey approaches that yield partial descriptions and do not reveal how obstacles interact during learning processes (27, 28). Second, observation instruments such as the Reformed Teaching Observation Protocol use broad indicators and may not capture didactical obstacles specific to fraction topics, such as unit framing, representational control and explicit institutionalisation (29). Third, the Indonesian context remains underrepresented in fine-grained analyses that connect classroom situations to students' representational activity and obstacle development. This limitation matters because Indonesia combines a uniform national curriculum with varied learning outcomes and persistently low mathematics literacy performance in international assessments (3). Evidence also indicates that many errors reflect weak prerequisites, so this context offers a strong setting for analyzing how prerequisite limits and classroom conditions jointly shape fraction obstacles (30).

To address these gaps, this study investigates the configuration and interaction of ontogenic, epistemological and didactical obstacles in Indonesian junior secondary students' learning of the part-whole fraction subconstruct. The study uses an integrated theoretical framework that connects the Theory of Didactic Situations, semiotic representation registers and epistemological obstacle theory (18-21). TDS frames learning as students' adaptive activity within a milieu shaped by tasks, representations, feedback and classroom norms (18). Representation-register analysis focuses on treatments within registers and conversions across registers, allowing the study to locate where representational breakdown signals obstacle manifestation (17, 31). Epistemological obstacle theory guides the identification of stable reasoning that persists across tasks and representations and resists immediate correction, with whole-number bias treated as a candidate epistemological obstacle in fraction learning (8, 21, 32). This integrated framework strengthens analytical transparency by linking data selection, coding procedures, theoretical references and reported results (33).

This study addresses the following research questions:

(a) What ontogenic and epistemological obstacles characterize students' understanding of part-whole fractions, as evidenced in their reasoning, error patterns and representational treatments and conversions?

(b) What didactical obstacles emerge from instructional practices, analysed through TDS phases and didactical contract indicators in fraction lessons?

(c) How do ontogenic, epistemological and didactical obstacles interact across didactical episodes and through what mechanisms do didactical choices mitigate or amplify students' cognitive obstacles?

Methodology

Research Design

This study used an exploratory embedded single-case study design to examine how ontogenic, epistemological and didactical obstacles were configured and interacted in part-whole fraction learning (34). The bounded case is Grade 7 instruction on the part-whole fraction subconstruct in Makassar, South Sulawesi and surrounding areas during one instructional unit (February–June 2025). The design is exploratory because it aims to develop an in-depth explanation of obstacle profiles and interaction mechanisms rather than to test hypotheses. An embedded case study design was chosen because the study required coordinated analysis of student-level obstacle profiles and teacher-level didactical conditions within one bounded instructional case. This design was more appropriate than an ethnographic approach because the study did not aim to describe the broader culture of school communities and it was more appropriate than a design-based approach because the study did not implement or iteratively refine an instructional intervention. The twelve schools served as multiple sites within this single case, enabling analysis across varied instructional settings within a common case boundary.

The embedded design included two units of analysis. The first unit is 187 students, whose diagnostic responses and clinical interviews provide evidence for epistemological and ontogenic obstacles. The second unit is 12 mathematics teachers, whose instructional practices provide evidence for didactical obstacles analyzed through the Theory of Didactic Situations (18). Didactical episodes serve as analytical segments that connect student reasoning with instruction across data sources. The core TDS constructs were operationalized in the classroom analysis. The milieu referred to the instructional environment formed by fraction tasks, representations, teacher prompts, student responses and feedback opportunities. Devolution was identified when teachers transferred responsibility for solving a fraction task to students. Adidactical situations were identified when students worked on fraction tasks with limited direct teacher explanation, allowing their strategies and errors to emerge through interaction with the task. The didactic contract was examined through implicit classroom norms, including expected solution forms, teacher authority in validation and acceptable representations. Institutionalization was identified when teachers formalized students' work into accepted mathematical language, notation, or procedures. These constructs guided the Learning Observation Sheet and the coding of classroom episodes.

Participants and Sampling

Participants included 187 seventh-grade students aged 12–15 years and 12 mathematics teachers from 12 junior secondary schools. The study used stratified cluster random sampling. Schools were selected across three geographical strata: urban Makassar (four schools; approximate GPS range: -5.182655 to -5.082566 latitude, 119.409131 to 119.518750 longitude), suburban Greater Makassar and surrounding districts (four schools; approximate GPS range: -5.462850 to -4.820694 latitude, 119.452078 to 119.580966 longitude) and rural districts outside Makassar (four schools; approximate GPS range: -5.120425 to -3.938937 latitude, 119.590282 to 120.304816 longitude). Within each stratum, schools were stratified by institutional status (public/private) and national accreditation level (A/B) to capture variation in instructional settings. This sampling structure allowed the study to examine obstacle patterns across urban, suburban and rural school contexts, as well as across public and private institutional settings. Within each selected school, one intact Grade 7 classroom was randomly selected as a cluster and all students in the selected classroom were invited to participate subject to consent and inclusion criteria. Student inclusion criteria were enrollment in Grade 7 during the 2024/2025 academic year and the ability to participate meaningfully in the study activities. Students who could not complete the Diagnostic Test of Fraction Representation or participate meaningfully in follow-up research activities were excluded. The 12 teachers (7 female, 5 male) hold bachelor's degrees in mathematics education and have 10–20 years of teaching experience. Participant and school-area characteristics are presented in Table 1.

Table 1: Participant Characteristics

Characteristic	Category	Number	Percentage (%)
Gender	Male	89	47.6
	Female	98	52.4
Age	13 years	47	25.1
	14 years	91	48.7
	15 years	49	26.2
Region	Urban	74	39.6
	Suburban	62	33.2
	Rural	51	27.3
School Status	Public	105	56.1
	Private	82	43.9
Accreditation	A	103	55.1
	B	84	44.9

Research Instruments

Diagnostic Test of Fraction Representation (DTFR). The Diagnostic Test of Fraction Representation (DTFR) consists of 12 multiple-choice items with written justifications. Items are distributed across three representational modes (area model, set model, number line; four items each) and three cognitive levels based on revised Bloom's taxonomy (understanding, application, analysis; 5, 4 and 3 items respectively). This structure supports exploratory profiling of whether obstacle indicators concentrate in specific representations or recur across modes.

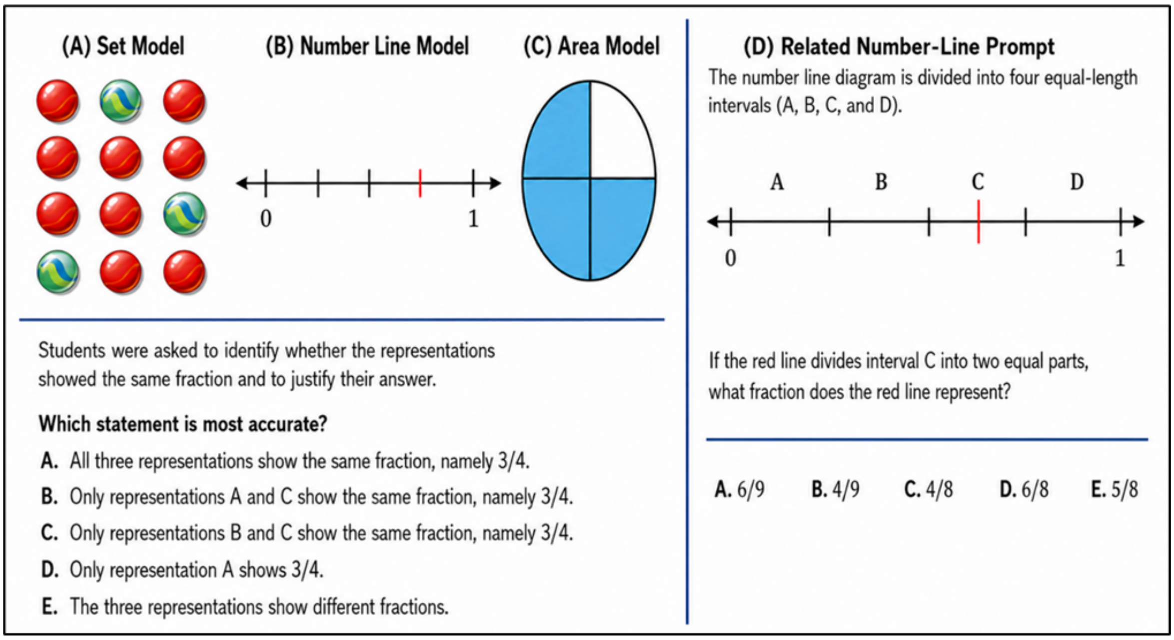

Figure 1: Sample Diagnostic Test of Fraction Representation Item. (A) Set Model, (B) Number Line Model, (C) Area Model, (D) Related Number-Line Prompt

The DTFR was developed based on Lesh's translation model (17) and was designed to elicit evidence of natural number bias and unit-related difficulties in part-whole reasoning. Written justifications provide evidence of students' reasoning patterns underlying responses and support identification of stable error patterns. Three mathematics education experts evaluated content validity using the Content Validity Ratio procedure (CVR = 0.89).

A pilot test with 30 students yielded Cronbach's alpha = 0.86. A sample DTFR item is shown in Figure 1. The item consists of four panels:

(A) a set model,
(B) a number line model,
(C) an area model and
(D) a related number-line prompt.

Students were asked to identify whether the representations in panels A, B and C showed the same fraction and to justify their answer. Figure 1 also includes a related number-line prompt in which students determined the fraction represented by a red line within a subdivided interval.

Learning Observation Sheet (LOS): The Learning Observation Sheet (LOS) is a structured observation tool that documents instructional conditions that may generate or sustain didactical obstacles and didactical contract effects. Aligned with the Theory of Didactic Situations (18), the LOS captures classroom activity across devolution, action, formulation, validation and institutionalization phases, along with didactical contract indicators (expected solution forms, authority patterns and implicit representational expectations), representational diversity and precision of mathematical language. Each session was video-recorded to support traceability and post-hoc microanalysis of critical instructional moments.

Semi-structured Clinical Interview Protocol: Student interviews used the Critical Incident Technique to probe reasoning linked to specific DTFR errors and observed classroom incidents (35). Prompts targeted unit definition, equipartitioning, numerator-denominator coordination, translation across representations and interpretation of instructional language. Teacher interviews targeted instructional decision-making, including rationales for representational choices, responses to errors, feedback norms and institutionalization moves. Interviews triangulated evidence from DTFR responses, LOS documentation and classroom video.

Data Collection Procedure

Data collection took place between February and June 2025 in three phases. In Phase 1, students completed the DTFR individually in a 90-minute session before formal instruction on fractions to document initial representational profiles. In Phase 2, each teacher was video-recorded during four to six Grade 7 lessons on part-whole fractions, with each lesson lasting about 80 minutes. Observers completed the LOS during lessons and flagged critical incidents for subsequent microanalysis. In Phase 3, twenty-four students were selected purposively using maximum variation based on DTFR profiles, including students with primarily epistemological indicators, primarily ontogenic indicators and combined obstacle indicators. Six teachers were interviewed to triangulate observation-based interpretations with teacher rationales. Interviews continued until no new codes emerged across consecutive interviews.

Data Analysis Procedures

The analysis integrated descriptive profiling of DTFR responses with theory-driven qualitative analysis of observation and interview data, applying theoretical references explicitly to generate results (33).

DTFR Analysis: DTFR responses were coded using a theory-driven codebook. Epistemological obstacle indicators related to natural number bias included whole-number comparison, denominator-as-whole-number interpretations, component-wise operation overgeneralization and magnitude misunderstanding. Ontogenic obstacle indicators included equipartitioning failures, unit conservation errors, abstraction limitations and spatial coordination difficulties. Frequencies and percentages were computed using SPSS 26 to describe code prevalence overall, by representational mode and by cognitive level, while the interpretation remained exploratory.

Classroom Analysis: Classroom video and LOS data were analyzed using an episode-based approach grounded in the Theory of Didactic Situations (18). Lessons were segmented into didactical episodes and coded by TDS phases: devolution, action, formulation, validation and institutionalization. Episodes were also coded for didactical contract indicators, including procedural expectations, authority patterns in validation and implicit representational expectations. Didactical obstacles were identified when task structure, representational privileging, feedback patterns, or contract norms constrained students' opportunities for formulation and validation or weakened coherent unit construction.

Interview Analysis: Interview transcripts were analyzed thematically to validate DTFR-based codes, explain stable reasoning patterns and capture students' interpretations of classroom expectations (36). Coding proceeded in two passes. The first pass used open coding to locate relevant reasoning segments and critical incidents. The second pass applied the same epistemological and ontogenic codes to enable direct comparison between written and verbal evidence, while retaining in vivo expressions when students' wording reflected stable interpretations.

Interaction Analysis: Interaction analysis used joint displays that integrated student profiles and instructional conditions. A matrix linked each student's obstacle profile from DTFR and interviews with didactical conditions observed in the student's lesson episodes. Evidence statements were supported by episode excerpts and interview segments. To reduce researcher over-interpretation, interaction claims were made only when evidence converged across at least two data sources. Recurring links were examined to articulate interaction mechanisms by tracing instructional conditions, representational demands or constraints and the stability or shift of students' reasoning across tasks and representations. Representational evidence was interpreted as treatments within registers and conversions across registers (17, 31).

Quality Assurance and Trustworthiness

Four researchers coded data using shared codebooks and explicit decision rules. A subset of DTFR responses, interview transcripts and lesson episodes was double-coded. Inter-rater reliability was assessed using Cohen's kappa with a target of $\kappa \geq 0.80$. Discrepancies were resolved through consensus meetings and documented codebook refinements. The study maintained an audit trail of episode segmentation, codebook versions, analytic memos and joint displays to support dependability and confirmability. Credibility was strengthened through triangulation across DTFR responses, classroom observations and interviews, as well as source and theoretical triangulation. Researcher reflexivity was also maintained throughout the study. The researchers recognized that their background in mathematics education could influence the interpretation of student errors and classroom practices. To minimize this bias, coding decisions were based on explicit indicators, multiple data sources, consensus discussions and documented analytic memos. Interpretations were not based on single observations but on recurring evidence across diagnostic responses, interviews and classroom episodes.

Results

This section reports obstacles in learning part-whole fractions using three analytic categories: epistemological obstacles (knowledge interference), ontogenic obstacles (developmental limitations) and didactical obstacles (instructional design). The analysis identifies systematic interactions among these obstacles. It interprets these interactions using Brousseau's Theory of Didactic Situations (TDS), which treats the classroom as a system where student reasoning and instructional practices jointly shape learning opportunities (18). The study triangulated evidence from the Diagnostic Test of Fraction Representation (DTFR, N = 187), classroom observations of 12 teachers and clinical interviews. To strengthen empirical grounding, the results include direct student explanations, representative response patterns and classroom observation evidence. Student excerpts are reported anonymously and are used to illustrate recurring coded patterns rather than isolated individual cases.

Data Presentation Note: Percentages indicate the prevalence of a coded pattern in the relevant sample (students for DTFR patterns, teachers for observation patterns). Participants could show multiple patterns, so percentages do not sum to 100%. Student codes required corroboration across DTFR and interview evidence. Teacher codes required recurrence across observations. Because the study involved schools from urban, suburban and rural areas and included both public and private schools, contextual variation was considered during interpretation. However, the study did not aim to make statistical comparisons between these groups; rather, the contextual categories were used to support analytic variation within the embedded case.

Epistemological Obstacles: Natural Number Bias and Its Manifestations

Natural number bias, defined as overgeneralization of whole-number reasoning to fractions, was the most prevalent epistemological obstacle. The analysis identified it in 106 students (56.7%). DTFR and interviews show distinct mechanisms across key fraction tasks.

Magnitude Comparison: Two dominant patterns emerged. First, 94 students (50.3%) showed the Denominator-as-Whole Number Error (ENB-COMP-1). They compared unit fractions by treating denominators as magnitudes, for example judging 1/5 as greater than 1/4. Interview evidence showed that students applied the whole-number heuristic "larger numbers mean larger quantities" and did not invert it for unit fractions. One student stated, "One-fifth is larger because five is bigger than four," then noticed a conflict after drawing circles but returned to the numerical cue. This response illustrates how a correct visual check did not immediately override the student's whole-number heuristic.

Second, 82 students (43.9%) used Separate Numerator-Denominator Comparison (ENB-COMP-2). They treated a fraction as two unrelated whole numbers, for example judging 3/7 as greater than 2/5 because 3 > 2. This pattern indicates a fragmented interpretation of fraction notation.

Operational Overgeneralization: In operational contexts, 73 students (39.0%) showed the Fraction as Two Whole Numbers error (ENB-OPER). They performed component-wise operations on numerators and denominators. This pattern often persisted even when students produced correct visual representations, suggesting that symbolic processing triggered a return to whole-number routines. For example, a student shaded 3/4 correctly but solved 3/4+1/4 by adding numerators and denominators to obtain 4/8.

Representational Constraints: As detailed in Table 2, many students showed representation-dependent performance. Eighty-eight students (47.1%) showed Limited Representation Dependency (ENB-REP-1). These students succeeded with familiar area models but failed when the same part-whole relation was presented through set models. This pattern suggests that discrete counting cues can override part-whole reasoning in collections. In addition, 79 students (42.2%) showed Number Line Misconceptions (ENB-REP-2). They misread tick marks using whole-number interpretations, which disrupted magnitude comparison and fraction placement on the number line.

Terminology and Part-Whole relation Errors: Students also misinterpreted fraction symbols and language. Seventy-seven students (41.2%) showed Reversal of Numerator and Denominator in explanations (ENB-TERM-1). Sixty-nine students (36.9%) showed Failure of Part-Whole Relation (ENB-TERM-2). They did not express "3 out of 4 equal parts" as one coordinated relationship and instead treated the two numbers as separate labels.

Table 2: Epistemological Obstacles. Natural Number Bias Error Patterns (N = 187)

Code	Error Pattern	n	%	Theoretical Mechanism	Representative Evidence
ENB-COMP-1	Denominator-as-Whole Number Error	94	50.3	Inappropriate application of the whole-number principle ("larger number means larger quantity") to unit fraction denominators, without inversion.	"Students concluded that 1/5 is greater than 1/4 because they compared the denominators as whole numbers: '5 is greater than 4.'"
ENB-COMP-2	Separate Numerator–Denominator Comparison	82	43.9	Treating the fraction notation as two independent whole numbers rather than a unified relational quantity.	"When comparing 3/7 and 2/5, students compared the numerators and denominators separately, concluding 3/7 is larger because 3 > 2."
ENB-OPER	Fraction as Two Whole Numbers	73	39.0	Applying whole-number arithmetic operations independently to the numerator and denominator, disregarding the part-whole relationship.	"Students treated the fraction 3/4 as two independent whole numbers, reading it as 'three and four' and performing operations such as 3 + 4 = 7."

ENB-REP-1	Limited Representation Dependency	88	47.1	Natural number bias, rooted in discrete counting, impedes the application of part-whole reasoning to discrete sets (set models).	"Students could show ¼ of a cake (area model) but got confused when asked to show ¼ of a set of 12 marbles (set model)."
ENB-REP-2	Number Line Misconception	79	42.2	Misinterpreting fraction notation on a number line by treating tick marks as whole-number points, failing to coordinate partitioning with the unit interval.	"Students understood ½ as 'half a cake' but did not understand that ½ also represents a point on the number line between 0 and 1."
ENB-TERM-1	Reversal of Numerator and Denominator	77	41.2	Confusion in interpreting the roles of numerator and denominator, often linked to unstable institutionalization of division terminology.	"Students misinterpreted the division operation, explaining ¾ as 'four divided by three' (4 ÷ 3) instead of 'three divided by four' (3 ÷ 4)."
ENB-TERM-2	Failure of Part–Whole Relation	69	36.9	Inability to articulate the coordinated relationship "a parts out of b equal parts"; treating numerator and denominator as separate labels.	Students described 3/4 as ‘three and four’ or ‘3 and 4’ without explaining it as three parts out of four equal parts of the same whole

Note: n= Number of Participants, % = Percentage.

Ontogenic Obstacles: Developmental Cognitive Limitations

Ontogenic obstacles, summarized in Table 3, were identified in 117 students (62.6%). These obstacles reflect limitations in cognitive readiness and prerequisite structures that are not yet stabilized, rather than the application of incorrect prior knowledge.

Spatial Partitioning: As detailed in Table 3, Unequal Partitioning (ONT-PART-1) was the most frequent ontogenic limitation, found in 89 students (47.6%). Students produced unequal parts while asserting equality. Interview evidence showed that many students equated “equal parts” with an equal number of parts and did not coordinate equality with area or quantity. One student drew a circle divided into four unequal regions and justified it by saying, “Yes, there are four parts,” then added, “I don’t know how to make them the same size,” when asked about equality. This excerpt shows that the student counted the number of parts but had not yet coordinated equality with area or quantity. Other partitioning-related patterns also appeared. Incorrect Proportional Representation (ONT-PART-2) was coded in 40.6% of students, indicating difficulty representing fractional quantities proportionally within a whole. Rigid Spatial Orientation (ONT-PART-3) appeared in 27.8% of students, where students accepted only canonical placements, for example insisting that 1/4 must occupy a specific quadrant position.

Abstraction and Transfer: Many students showed Context-bound Understanding (ONT-ABS-1, 52.4%). They succeeded in familiar contexts but did not transfer reasoning to more abstract settings. Isolated Relational Understanding (ONT-ABS-2, 45.5%) emerged when students recognized that two representations, such as 1/2 and 2/4, looked the same, yet rejected equivalence because “the numbers are different.” This pattern indicates difficulty construing equivalence as an abstract relation across symbolic forms.

Unit Conservation: Unit-related instability, also summarized in Table 3, was a central ontogenic difficulty. Shifting Unit Reference (ONT-UNIT-1) occurred in 35.8% of students, where students redefined the whole after partitioning, for example treating each piece as “a whole” after cutting a cake into four parts. Size-dependent Reasoning (ONT-UNIT-2) was coded in 32.6% of students, indicating reliance on visible size cues rather than a stable unit definition. Inconsistent Whole Reference (ONT-UNIT-3) appeared in 31.0% of students, showing shifts in the referent whole across tasks that undermined coherence in part-whole reasoning.

Table 3: Ontogenic Obstacles: Developmental Cognitive Limitations (N = 187)

Code	Obstacle Type	n	%	Cognitive Mechanism	Representative Evidence
ONT-PART-1	Unequal Partitioning	89	47.6	Underdeveloped spatial-geometric schema for creating equal parts; conflates equality of count with equality of area or quantity.	"Students drew a circle divided into four parts of unequal size, yet labeled one part as ¼."
ONT-PART-2	Incorrect Proportional Representation	76	40.6	Weak proportional reasoning; inability to coordinate the relationship between the shaded area and the stated fraction magnitude.	"When asked to draw two identical circles representing ½ and ¾, students shaded a smaller area for ¾ than for ½."
ONT-PART-3	Rigid Spatial Orientation	52	27.8	Understanding of fractions is tied to prototypical visual templates; lack of flexibility in recognizing equivalent spatial arrangements.	"Students stated that the shading for ¼ is only valid if located in the upper-right quadrant of the circle."
ONT-ABS-1	Context-bound Understanding	98	52.4	Difficulty in decontextualizing the part-whole structure; conceptual understanding is coupled to familiar concrete instantiations.	"Students could correctly show ¾ of a divided box but failed to apply the same concept to ¾ of an hour (45 minutes)."
ONT-ABS-2	Isolated Relational Understanding	85	45.5	Inability to construct equivalence as an abstract mathematical relation; reasoning is dominated by surface features (different numerals).	"Students saw images of ½ and 2/4 as having the same area, yet insisted that ½ ≠ 2/4 because 'the numbers are different'."
ONT-ABS-3	Concrete-to-Abstract Transition Difficulty	71	38.0	Developmental gap in transferring an operation or relationship from a concrete, enacted context to a symbolic or representational system.	"Students could divide a cake into three equal parts to show ⅓ but struggled to mark ⅓ on a number line representing 0 to 1."
ONT-UNIT-1	Shifting Unit Reference	67	35.8	Lack of conservation of the referent whole; redefines the "whole" after a physical partition, treating each part as a new unit.	"After a whole cake was divided into four parts, students considered one slice as a 'new whole,' not as part of the original whole."
ONT-UNIT-2	Size-dependent Reasoning	61	32.6	Judging the value of a fraction by the absolute size of the part rather than its relational proportion to the whole.	"Students argued that ½ of a large pizza is 'bigger' than ½ of a small pizza, thus assuming the fractions had different values."
ONT-UNIT-3	Inconsistent Whole Reference	58	31.0	Unstable coordination of the referent whole within and across problems; the "whole" shifts implicitly during reasoning.	"Within the same problem, students shifted the referent whole from '4 apples' to '1 apple' without explicit acknowledgment, leading to inconsistent interpretations."

Note: n= Number of Participants, % = Percentage. Individual students could exhibit multiple obstacles; therefore, percentages are not mutually exclusive and do not sum to 100%.

Didactical Obstacles: Instructional Practices Through the Lens of TDS

Classroom observations analyzed through TDS identified systemic didactical obstacles, as summarized in Table 4, in 11 of 12 teachers (91.7%). In TDS terms, these obstacles arise when teaching practices structure the milieu in ways that limit opportunities for students to construct, communicate and validate fraction meanings.

Critical Imbalance: Lesson-time analysis showed a strong imbalance. Teacher explanation consumed a mean of 68.9% of lesson time. Adidactic situations received limited time: Action (M = 12.3%, SD = 4.7), Formulation (M = 8.1%, SD = 3.2) and Validation (M = 3.4%, SD = 2.1). Administrative and transition time averaged 7.3%. This distribution reduced opportunities for students to explore strategies, express reasoning and justify claims about fractions.

Didactical Contract Violations: Recurrent implicit norms functioned as obstacles and constrained formulation and validation, as shown in Table 4. Procedural Sufficiency Norm appeared when teachers accepted correct answers without probing conceptual justification (DO-DC-1; 11 teachers, 91.7%). Representational Monotony appeared when instruction relied heavily on food-based area models, with limited use of set models, number lines, or varied shapes (DO-DC-2; 11 teachers, 91.7%). Fair Sharing Ambiguity appeared when teachers used prompts such as 'divide equally' without operationalizing equality, for example equal area or equal quantity, allowing misconceptions to persist (DO-DC-3; 11 teachers, 91.7%). Single-Answer Expectation and Product-over-Process Evaluation narrowed mathematical validity to matching the teacher's model and reduced the status of student reasoning (DO-DC-4; 9 teachers, 75.0%; DO-DC-5; 8 teachers, 66.7%).

Premature or Problematic Institutionalization: Teachers often institutionalized meanings too early or in ways that increased interference between whole-number and fraction reasoning. Division terminology premature institutionalization occurred when early introduction of "3/4 = three divided by four" could activate whole-number division schemas and align with ENB-OPER (DO-INST-1; 11 teachers, 91.7%). Premature symbolic transition occurred when teachers shifted to a/b notation after limited exploration with concrete or varied representations, leaving symbols weakly grounded in part-whole meaning (DO-INST-2; 7 teachers, 58.3%).

Sequencing Issues: The analysis also identified sequencing issues that weakened connections across representations. Many teachers introduced area models and number lines with limited bridging tasks, which restricted cross-representational coordination (DO-SEQ-1; 10 teachers, 83.3%). Many teachers also introduced procedures before consolidating part-whole meaning, which promoted procedural routines without conceptual grounding (DO-SEQ-2; 10 teachers, 83.3%).

Table 4: Didactical Obstacles Analyzed Through Theory of Didactic Situations (N = 12 Teachers)

Code	Obstacle Type	Didactical Obstacle	n	%	TDS Component Affected	Mechanism
DO-DC-1	Didactic Contract Violation	Procedural Sufficiency Norm	11	91.7	Formulation, Validation	Accepting correct answers without probing justification eliminates the need for students to articulate or validate reasoning, reducing situations of formulation and validation.
DO-DC-2	Didactic Contract Violation	Representational Monotony	11	91.7	Action, Formulation	Heavy reliance on a narrow set of models (e.g., food-based circles) restricts the milieu. Students lack opportunities for action and formulation across diverse representational systems, hindering abstraction.
DO-DC-3	Didactic Contract Violation	Fair Sharing Ambiguity	11	91.7	Formulation, Institutionalization	Using "divide equally" without operationalizing "equality" (as equal area/quantity) leaves the didactic contract implicit. Students construct alternative, often incorrect, definitions that are never formally challenged or rectified.
DO-DC-4	Didactic Contract Violation	Single-Answer Expectation	9	75.0	Validation	Establishing only one representation as valid contradicts the mathematical reality of multiple equivalent forms. This constrains validation situations and students' understanding of mathematical equivalence.

DO-DC-5	Didactic Contract Violation	Product-over-Process Evaluation	8	66.7	Validation	Focusing assessment solely on the final product (answer) rather than the reasoning process removes the necessity for validation. This allows contradictory knowledge systems to persist without reconciliation.
DO-INST-1	Premature/Problematic Institutionalization	Division Terminology Premature Institutionalization	11	91.7	Institutionalization	Institutionalizing "a/b = a divided by b" before part-whole meaning is stabilized legitimizes the activation of students' whole-number division schemas, potentially triggering epistemological interference (ENB-OPER).
DO-INST-2	Premature/Problematic Institutionalization	Premature Symbolic Transition	7	58.3	Institutionalization	Moving to abstract a/b notation after minimal concrete exploration means symbols are institutionalized before the concepts they represent are constructed through adequate action/formulation situations, leading to procedurally driven understanding.
DO-SEQ-1	Instructional Sequencing Issue	Representation Sequence Gap	10	83.3	Milieu Design	Introducing representations (e.g., area models vs. number lines) with a significant instructional gap prevents students from constructing connections between them, as the milieu is not designed to foster cross-representational coordination.
DO-SEQ-2	Instructional Sequencing Issue	Procedure-before-Concept Approach	10	83.3	Chronogenesis	Introducing procedural algorithms (e.g., common denominator addition) before conceptual grounding rushes the chronogenesis. Students lack the conceptual basis (constructed through prior adidactic situations) to make sense of the procedures.

Note: n= Number of Participants, % = Percentage.Individual teachers could exhibit multiple obstacles; therefore, percentages are not mutually exclusive and do not sum to 100%.

Obstacle Interactions: Mechanisms Revealed Through Triangulation

Triangulation of DTFR profiles, classroom observations and interviews shows that obstacles co-occur and interact through identifiable mechanisms when the classroom is treated as a didactic system in TDS. The interaction claims relied on convergent evidence from LOS patterns, aggregated DTFR profiles by classroom and interview excerpts, as illustrated by the cases in Table 5.

Mechanism 1: Representational Monotony Amplifies Abstraction Limits

Students in classrooms coded with Representational Monotony (DO-DC-2) showed higher rates of Context-bound Understanding (ONT-ABS-1) than students in classrooms with more representational diversity (59.0% vs. 35.8%). A restricted milieu limits opportunities for coordination across representations. Part-whole meaning then remains tied to familiar contexts and does not stabilize as a transferable schema. DTFR profiles in these classrooms showed success on area-model items but failure on set-model and number-line items (ENB-REP-1, ENB-REP-2). Interviews confirmed dependence on familiar pictures. One student stated, "I don't understand. Marbles aren't cakes." This statement illustrates how students who succeeded with area models could fail to transfer the same part-whole relation to set models.

Mechanism 2: Didactical Contract Norms Sustain Epistemological Bias

In classrooms with Product-over-Process Evaluation (DO-DC-5), students often maintained contradictory patterns: correct visual intuition alongside persistent natural number bias in symbolic tasks. When classroom norms accept correct products without requiring formulation and validation, students can retain parallel knowledge systems without confronting inconsistencies. DTFR profiles showed students who succeeded on shaded-area tasks but displayed ENB-OPER in symbolic operations. Interviews indicated that students separated "visual" routines from "number" routines and followed classroom expectations for symbolic work.

Mechanism 3: Premature Institutionalization Triggers Interference.

Classrooms that institutionalized division terminology early (DO-INST-1) showed a higher prevalence of ENB-OPER than the classroom that emphasized part-whole terminology more consistently (42.0% vs. 20.0%). Institutionalizing "a/b = a divided by b" before stabilizing part-whole meaning legitimizes activation of whole-number division schemas and can trigger the interference it aims to prevent. DTFR responses and interviews showed that students reproduced "divided by" language but failed to maintain coordinated part-whole meaning across changing representations. ENB-TERM-1 and ENB-TERM-2 appeared as language-driven compensations for unstable meanings.

Mechanism 4: Limited Action Situations Constrain Ontogenic Development

Equipartitioning failures (ONT-PART-1) were highly prevalent in classrooms where hands-on partitioning formed less than 10% of lesson time. One classroom that allocated substantial time to action situations (28%) showed a lower rate of this obstacle. In TDS terms, equipartitioning develops through interaction with a milieu that provides immediate feedback, such as misaligned folds or unequal parts. When action situations are scarce, students lose access to this feedback and fail to stabilize the needed schema. DTFR and interviews also suggested a cascade. Students coded with ONT-PART-1 often also showed ONT-UNIT-1. This instability then undermined tasks requiring unit consistency, including number-line placement (ENB-REP-2) and part-whole explanations (ENB-TERM-2), as detailed in the interaction patterns in Table 5.

Table 5: Triangulated Cases of Obstacle Interactions

Case	Didactical Evidence (LOS)	Student Evidence (DTFR)	Interview Evidence	Interaction Pattern
A	DO-DC-2	ENB-REP-1, ENB-REP-2; ONT-ABS-1	Students explained that their reasoning depends on familiar contexts or representations.	Amplification
B	DO-DC-3; DO-INST-1	ENB-TERM-1, ENB-TERM-2	Students explained answers using keywords or rehearsed terminology rather than coordinated meanings.	Compensation
C	DO-SEQ-1; DO-DC-3	ONT-PART-1; ONT-UNIT-1; ENB-REP-2	Students described a difficulty sequence from partitioning to unit coordination and then to number line placement.	Cascade
D	DO-DC-5; DO-SEQ-2; DO-INST-2	ENB-OPER; ONT-ABS-2	Students reported that visual tasks and symbolic tasks feel unrelated, leading to correct visuals but incorrect symbols.	Mutual reinforcement

Note: Table 5 summarizes recurring triangulation patterns derived from the triangulation matrix

Discussion

This study suggests that students' difficulties in part-whole fractions emerge from the interaction of epistemological, ontogenic and didactical obstacles, rather than from student limitations alone (37, 38). Using the Theory of Didactic Situations, these obstacles are interpreted as features of a didactic system. Teachers' instructional choices shape the milieu and the didactical contract, which influence students' opportunities for action, formulation and validation (18, 38).

These findings are consistent with recent international literature showing that fraction misconceptions are often linked to natural number bias, limited representational fluency and weak coordination across visual, symbolic and contextual forms (7, 24, 27, 37, 39-42). Recent studies also emphasize that students' conceptual understanding of rational numbers becomes visible through their use of and shifts between representations and that multimodal mathematical learning requires students to coordinate information across visual, symbolic, verbal and contextual forms (40, 41). The present study extends this literature by showing how such cognitive and representational difficulties may be sustained by classroom norms, task sequencing, institutionalization timing and limited opportunities to validate meanings across representations. Four mechanisms explain the interactions observed. First, representational monotony, especially heavy use of food-based area models (DO-DC-2; 91.7% of teachers), restricted the milieu and amplified abstraction limits. Students in these classrooms showed more context-bound understanding (ONT-ABS-1) than students in classrooms with more representational diversity (59.0% vs. 35.8%). Students often succeeded on area-model tasks but struggled with set models and number lines (ENB-REP-1, ENB-REP-2). This pattern indicates that limited representational experience can prevent cross-representational coordination and weaken generalization (18, 24, 39).

Second, didactic contract norms sustained epistemological interference when teachers valued answers over reasons. Product-over-process evaluation (DO-DC-5) reduced demands for explanation and validation, so students could keep inconsistent rules: correct visual judgments but whole-number routines in symbolic work. Interview evidence showed that students often separated visual reasoning from symbolic routines when classroom norms emphasized answers rather than justification. This mechanism specifies how didactical contract norms can maintain natural number bias when validation across representations is not required (18, 43).

Third, premature institutionalization triggered whole-number interference. Early framing of a/b as division was common (DO-INST-1; 91.7% of teachers) and associated with higher component-wise operation errors (ENB-OPER; 42.0% vs. 20.0%). In TDS terms, institutionalization defines legitimate meanings. When teachers institutionalize division language before part-whole meaning is stabilized, they may legitimize whole-number division schemas and activate the interference they intend to reduce (18).

Fourth, weak sequencing produced fragmented concepts and blocked construction of key invariants. Gaps between area models and number lines (DO-SEQ-1) and procedure-before-concept approaches (DO-SEQ-2) left core prerequisites unresolved, especially equipartitioning and stable unit reference (ONT-PART-1; ONT-UNIT-1). These unresolved constraints then propagated into later difficulties, including equivalence reasoning (ONT-ABS-2) and number-line placement and magnitude interpretation (ENB-REP-2). This aligns with evidence that early and integrated number-line work supports magnitude understanding and cross-representational coordination (2). The variation across urban, suburban, rural, public and private school contexts suggests that the identified obstacles were not confined to a single school type. Nevertheless, the study treats these contextual categories as analytic variation rather than as variables for inferential comparison. This interpretation is consistent with the embedded case study design, which emphasizes mechanism identification across varied settings within one bounded case.

The study contributes a triangulated, system-level account that links student obstacle profiles to classroom-level didactical conditions through explicit interaction mechanisms. This moves beyond listing errors and supports a non-deficit interpretation in which persistent misconceptions can reflect a didactic system that limits opportunities for cognitive conflict, explanation and restructuring (8, 18).

The findings imply the need for coordinated instructional redesign. Instruction should integrate area, set and number-line representations early and require students to translate and justify across them (24, 39). Teachers should shift classroom norms so that answers require brief justification and validation, rather than procedural correctness alone (18, 43). Institutionalization should be delayed until students can explain part-whole meaning consistently across representations (18). Teacher education should prepare teachers to diagnose obstacle interactions and design TDS-informed adidactic tasks that anticipate and reduce the unintended reinforcement of whole-number bias (44, 45).

The uniqueness of this study lies in its integrated analysis of student obstacle profiles and classroom-level didactical conditions. Rather than treating fraction errors only as individual misconceptions, this study shows how natural number bias, weak equipartitioning, unstable unit reference, representational monotony, didactical contract norms and premature institutionalisation can operate together within one didactic system. This contribution strengthens the explanatory value of TDS for analysing fraction learning because it connects students' representational breakdowns with specific features of classroom instruction and interaction.

The findings should be interpreted mainly within the part-whole subconstruct. Some mechanisms identified in this study, such as natural number bias, unit instability and weak representational coordination, may also appear in other fraction meanings such as measure, quotient, ratio and operator. However, the present findings cannot be directly generalized to all fraction subconstructs because each meaning involves different conceptual demands and representational structures. Further studies are needed to examine whether similar obstacle interactions emerge across other fraction meanings. The case was bounded to Grade 7 fraction instruction in South Sulawesi, so the findings should be interpreted within this educational context.. The study also focused on the part-whole subconstruct and did not examine all meanings of fractions, such as ratio, operator, quotient and measure. Therefore, the findings cannot be directly generalized to all fraction subconstructs because each meaning involves different conceptual demands, representational structures and instructional trajectories. Future research could compare obstacle interactions across different fraction subconstructs, school contexts and instructional designs to test the transferability of the proposed interaction mechanisms.

Conclusion

This study shows that obstacles in part-whole fraction learning among Indonesian junior secondary students operate as an interconnected system rather than as isolated difficulties. Through triangulated analysis involving 187 students and 12 teachers, this study identified three categories of obstacles: epistemological obstacles rooted in natural number bias, which appeared in 56.7% of students; ontogenic obstacles reflecting developmental limitations in equipartitioning, abstraction and unit conservation, which appeared in 62.6% of students; and didactical obstacles in instructional design, which appeared in 91.7% of teachers.

These obstacles interacted through identifiable mechanisms supported by convergent evidence. Representational monotony in instruction, dominated by area models, was associated with higher context-bound understanding. Didactical contract norms that prioritized procedural correctness over conceptual justification appeared to sustain natural number bias by reducing opportunities for validation. Early institutionalization of division terminology was associated with stronger interference from whole-number schemas. Taken together, these results extend the use of Brousseau's Theory of Didactic Situations by showing how features of milieu design, didactical contract norms and institutionalization timing shape the conditions under which fraction-related obstacles emerge and persist.

Theoretically, this study contributes a systemic model that links student error patterns to properties of the didactic system. This positions persistent fraction errors as outcomes that may be didactically sustained, rather than merely as individual cognitive deficits. Practically, fraction instruction should integrate multiple representations, including area, set and number-line models; establish classroom norms that require students to formulate and validate reasoning; and sequence institutionalization so that symbolic formalization follows stable part-whole understanding.

This study is limited by its geographical scope in South Sulawesi, its cross-sectional design and its focus on the part-whole subconstruct. Future research should test TDS-informed instructional redesign experimentally, trace students' obstacle trajectories longitudinally, extend the analysis to other fraction subconstructs and examine whether the identified mechanisms can be replicated across different regions and cultural contexts.

Abbreviations

CVR: Content Validity Ratio, DTFR: Diagnostic Test of Fraction Representation, LOS: Learning Observation Sheet, PISA: Programme for International Student Assessment, SPSS: Statistical Package for the Social Sciences, TDS: Theory of Didactic Situations.

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Author Contributions

Sutamrin: Conceptualization, Methodology, Investigation, Formal Analysis, Validation, Manuscript Writing, Alimuddin Tampa: Conceptualization, Methodology, Investigation, Formal Analysis, Validation, Manuscript Writing, Supervision, Review, Editing, Khadijah: Conceptualization, Methodology, Investigation, Formal Analysis, Validation, Manuscript Writing, Abdurahman Hamid: Conceptualization, Methodology, Investigation, Formal Analysis, Validation, Manuscript Writing, Fauziyyah Alimuddin: Conceptualization, Methodology, Investigation, Formal Analysis, Validation, Manuscript Writing. All authors have read and approved the final version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declaration of Artificial Intelligence (AI) Assistance

During the writing and revision process of this manuscript, the authors used AI-based tools (ChatGPT and DeepSeek) solely for language refinement and grammar checking. No AI tools were used to generate research data, conduct data analysis, or make scientific interpretations. The authors have reviewed, edited and approved the final version of the manuscript and take full responsibility for its content.

Ethics Approval

This study received ethical approval from the Research Ethics Committee of Universitas Negeri Makassar. Informed consent was obtained from all participating teachers, while student assent was obtained after parental permission. All data were collected while maintaining the confidentiality of participant identities.

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