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Numeracy Didactical Design Based on Scaffolded Instruction to Overcome Learning Obstacles in Systems of Linear Inequalities: An Adversity Quotient Perspective

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Abstract

This study develops and evaluates a numeracy-focused didactical design that addresses high school students' learning obstacles in Systems of Linear Inequalities in Two Variables (SLITV) through scaffolded instruction differentiated by Adversity Quotient (AQ) profiles. The investigation employed an exploratory sequential mixed-methods approach, combining Didactical Design Research (DDR) at one school (6 students for obstacle identification; 3 for metapedadidactic analysis) with a quasi-experimental design at another (80 students: 40 experimental and 40 control). The qualitative phase identified six learning obstacle types with distinct AQ-based manifestations. Among Quitters, psychological barriers such as mathematics anxiety and learned helplessness functioned as root causes through an "obstacle cascade" mechanism. Campers exhibited a self-imposed "good enough" mentality despite adequate capability, whilst only curriculum limitations emerged among Climbers. The study developed a Hypothetical Didactical Design integrating Brousseau's Theory of Didactical Situations with a novel SCALE (Set up Goals, Contradict Adidactic, Anonymous Gallery, Lock-In, Evaluate/Extended) framework and three-tiered AQ-responsive scaffolding and iteratively refined it through metapedadidactic analysis, producing an Empirical Didactical Design with 16 new Didactical-Pedagogical Anticipations. The empirical design demonstrated strong effectiveness: Cohen's d = 1.687, experimental normalised gain of 0.82 (high) versus control of 0.67 (medium), classical completeness at 85%, implementation fidelity of 97% and student responses at 95.91% (very positive). This study contributes the first integration of AQ-responsive differentiation within DDR specifically targeting numeracy competencies in algebraic domains.

Keywords: Adversity Quotient, Didactical Design Research, Learning Obstacles, Numeracy, Scaffolded Instruction.

Introduction

The global educational landscape confronts a deep-rooted numeracy challenge with far-reaching consequences for economic development and civic participation. Numeracy, broadly defined as the capacity to access, apply, interpret and communicate mathematical information across diverse real-world contexts (1), has emerged as a foundational competency in an era marked by growing societal complexity and data-driven decision-making. Approximately 69% of learners in economically developing nations fall short of baseline mathematical proficiency, with Southeast Asian countries exhibiting particularly concerning patterns (1). Individuals with limited numeracy skills tend to make less informed health decisions, demonstrate lower financial capability and remain more susceptible to misleading information (2-4). Indonesia exemplifies this worldwide challenge, with PISA data revealing a decline in numeracy performance from 379 to 366 between 2018 and 2022, positioning Indonesia considerably below the OECD average by margins of 106 to 110 points, as presented in Table 1 (1). This decline prompted a shift from the National Examination toward the Minimum Competency Assessment (5). Regional inequalities further complicate matters: South Sulawesi Province exhibits numeracy development trailing national figures, with disparities widening from 9.52% in 2022 to 14.06% in 2024 (6). The most pronounced weakness lies in the change and relationship content domain, which encompasses algebraic topics including systems of linear inequalities in two variables (7). A preliminary study conducted from March to April 2025 with 68 Grade X students in Makassar City confirmed mean numeracy scores of only 44.5% with completion rates below 16%, with all participants exhibiting multiple learning obstacles categorised as epistemological, ontological and didactical obstacles (8-10).

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Table 1: Indonesia's PISA Numeracy Performance Compared with the OECD Average

Year	Indonesia	OECD Average	Gap
2018	379	489	-110
2022	366	472	-106

As shown in Table 1, Indonesia's PISA numeracy scores declined from 379 in 2018 to 366 in 2022, whilst the OECD average simultaneously decreased from 489 to 472. The persistent gap of approximately 106 to 110 points indicates that Indonesia's underperformance is not merely a consequence of a global downward trend but reflects deeper structural challenges in Mathematics education. These data underscore the urgency of developing targeted instructional interventions, such as the didactical design proposed in this study, to address the nation's numeracy deficit at its foundational levels.

Several theoretical and empirical frameworks address these challenges. Didactical Design Research (DDR) offers a rigorous approach for building research-driven pedagogical interventions through prospective analysis, metapeda-didactic examination and retrospective evaluation (10, 11). Scaffolded instruction, grounded in Vygotsky's Zone of Proximal Development, provides graduated support enabling learners to reach understanding beyond their independent capacity (12). Meta-analytic research has validated its effectiveness when teachers progressively withdraw support to cultivate autonomous learning (13, 14), whilst computer-based scaffolding shows differential effectiveness for individual versus group contexts (15). Additional evidence confirms that scaffolding strategies in STEM domains significantly improve problem-solving outcomes, particularly when tailored to learner characteristics (16). Meanwhile, Adversity Quotient (AQ), comprising Control, Origin and Ownership, Reach and Endurance dimensions (17), positively affects mathematical comprehendsion (18-20), with Climbers demonstrating stronger problem-solving performance compared to Quitters and Campers (21, 22). However, prior investigations have neither directly targeted numeracy competencies within DDR frameworks (23-26) nor systematically incorporated psychological attributes in addressing learning barriers, as Table 2 summarises.

Table 2: Comparative Analysis of Previous Research and Identified Gaps

Focus	AQ Integration	Numeracy Focus	Effect Size	LO Evidence	References
DDR methodology	No	No	N/A	Theoretical	(10)
Scaffolding meta-analysis	No	No	g = 0.776	Not coded	(13)
AQ and math understanding	Yes	No	r = 0.514	N/A	(18)
DDR for algebra	No	No	N/A	Coded	(27)
DDR + AQ + Scaffolding	Yes	Yes	d = 1.687	Fully coded	This Study

Table 2 reveals that previous studies have examined individual components of the present framework in isolation: DDR methodology without AQ integration (10), scaffolding meta-analyses without numeracy specificity (13) and AQ research without didactical design linkage in algebra (18, 27). None of these prior investigations simultaneously incorporated all three dimensions—AQ-responsive differentiation, DDR methodology and explicit numeracy targeting in algebra—nor did they produce fully coded learning obstacle evidence alongside quantitative effect sizes. This comparative mapping thus substantiates the novelty claim of the present study and clarifies the specific theoretical and empirical gaps it addresses.

The present study addresses these gaps by developing and assessing a didactical design anchored in scaffolded instruction, specifically aimed at strengthening numeracy within algebraic domains whilst attending to AQ variability.

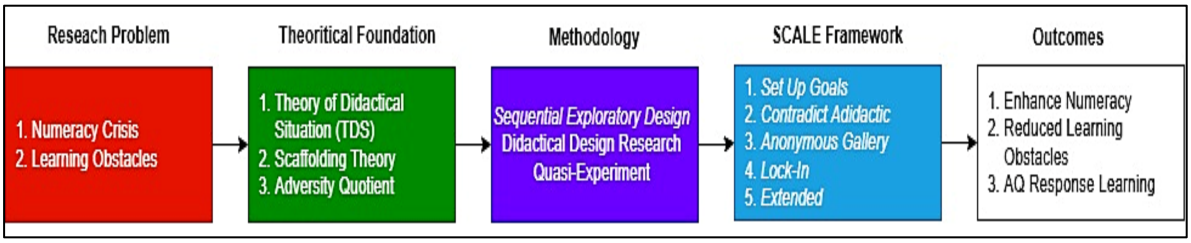

Figure 1: Conceptual Framework

Four research questions guide this inquiry: (RQ1) What learning obstacles do students experience based on AQ differences? (RQ2) How does the hypothetical didactical design develop? (RQ3) How does the metapedadidactic implementation proceed and what empirical design revisions emerge? (RQ4) How effective is the empirical didactical design in addressing learning obstacles? The novelty of this study lies in its first integration of AQ-responsive differentiation within the DDR framework, specifically targeting numeracy competencies in algebraic domains, thereby bridging the gap between didactical theory, socio-cultural scaffolding and individual difference psychology.

The theoretical foundation rests on three integrated pillars. First, Brousseau's Theory of Didactical Situations (TDS) provides a comprehensive framework for crafting Mathematics instruction informed by systematic investigation of learning barriers, distinguishing didactical from adidactical situations and identifying four dialectical situations: Action, Formulation, Validation and Institutionalisation (28-30). Learning obstacles emerge when knowledge effective within specific conditions proves insufficient in alternative settings, classified as ontogenic (cognitive maturation constraints), epistemological (inherent knowledge structure complexity) and didactical (instructtional shortcomings) (31-38). Second, scaffolding, initially described as supportive mechanisms enabling learners to perform within Vygotsky's Zone of Proximal Development (39), is characterised by contingency, fading and transfer of responsibility (40), with empirical confirmation of its capacity to strengthen mathematical reasoning (13, 39). Third, AQ classifications include Quitters (scores 36-85), Campers (scores 86-125) and Climbers (scores 126-144), with documented differential problem-solving patterns across profiles (18-22).

Methodology

This investigation employed an exploratory sequential mixed-methods approach (41, 42). The researchers selected this design because the research problem required initial qualitative exploration to identify and understand the nature of learning obstacles across AQ profiles before quantitative evaluation of intervention effectiveness could be meaningfully conducted. The sequential integration facilitated the creation of theory-driven, contextually verified interventions accompanied by rigorous outcome measurement. During the qualitative strand, DDR guided the construction of an Empirical Didactical Design (DDE) attuned to AQ characteristics across three iterative stages: prospective inquiry, metapedadidactic enactment and retrospective synthesis (10, 11). The quantitative strand applied a quasi-experimental framework with pretest and posttest comparison groups to evaluate DDE impact. Figure 2 depicts the overall research design.

Figure 2 presents the overall research design, showing the sequential integration of qualitative and quantitative strands within the exploratory sequential mixed-methods approach. The qualitative strand (DDR at SMAN 7 Makassar) progresses through three iterative stages—prospective analysis, metapedadidactic enactment and retrospective synthesis—producing the Empirical Didactical Design. This design is then evaluated through the quantitative strand (quasi-experimental at SMAN 21 Makassar), ensuring that intervention development and outcome measurement occur in complementary yet independent contexts to minimise contamination effects.

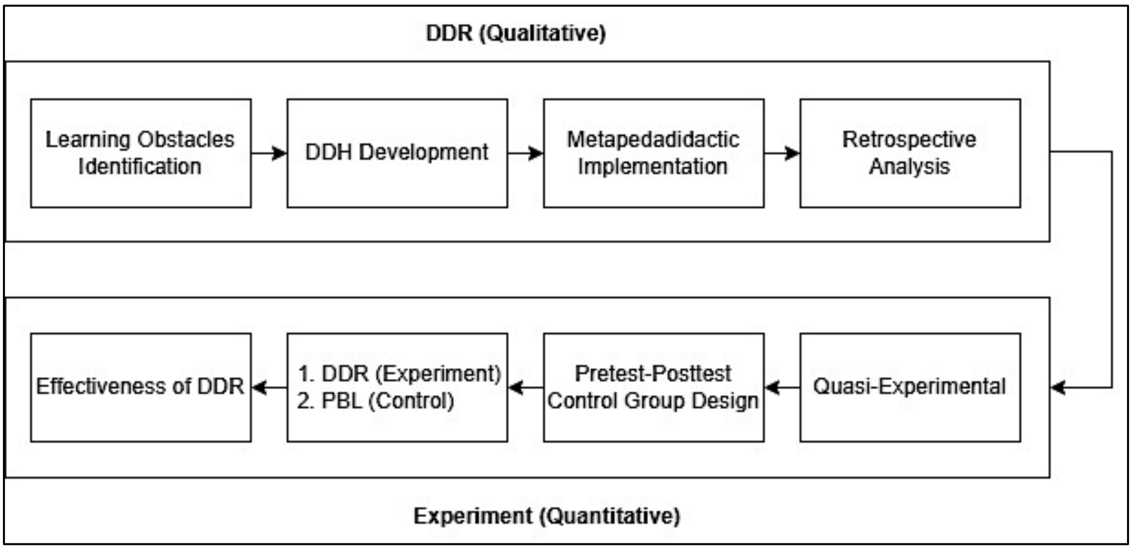

Figure 2: Research Design

Table 3: Didactical Design Research Stages

Stage	Duration	Key Activities	Output
Prospective Analysis	Weeks 1 - 4	Epistemological analysis; LO identification (6 students); DDH development with SCALE framework	Hypothetical Didactical Design (DDH)
Metapedadidactic	Weeks 5 - 8	DDH implementation across 4 Didactical Situations (SD1 - SD4); In-depth observation (3 students); Response documentation	Learning data; Student work artefacts; Coded transcripts
Retrospective	Weeks 9 - 10	DDH effectiveness analysis; AQ responsiveness evaluation; Design refinement; +16 new ADP	Empirical Didactical Design (DDE)

Table 3 outlines the temporal structure and methodological activities across the three DDR stages, spanning a total of ten weeks. The prospective analysis phase (Weeks 1–4) produced the Hypothetical Didactical Design through systematic epistemological analysis and learning obstacle identification with six purposively selected students. The metapedadidactic phase (Weeks 5–8) generated rich classroom data through in-depth observation of three representtative students, whilst the retrospective phase (Weeks 9–10) yielded the refined Empirical Didactical Design with 16 additional Didactical-Pedagogical Anticipations. This staged progression ensured that each design iteration was empirically grounded.

For the qualitative phase (DDR), the research team selected participants through purposive sampling based on AQ characteristics measured via the Adversity Response Profile (ARP), a 36-item self-report questionnaire adapted from the original instrument (17) with established reliability (Cronbach's α = 0.891). The sampling criteria required students who: (a) had previously completed instruction on linear inequalities systems, (b) represented distinct AQ categories (Quitter: 36 to 85; Camper: 86 to 125; Climber: 126 to 144) and (c) demonstrated willingness to participate in extended interviews and observations. From an initial pool of 68 students who completed the ARP, the team selected 6 Grade XII students at SMAN 7 Makassar (2 per AQ category: Quitter, Camper, Climber), balanced by gender to ensure representational diversity. Data collection comprised semi-structured in-depth interviews (15 protocol items), analysis of student work artefacts in solving SLITV problems with applicative contexts and process observation. The research team audio-recorded all interviews, transcribed them verbatim and coded them using a three-phase approach (43): data condensation with systematic alphanumeric identifiers (e.g., QL3 for Quitter-Male response 3, where Q = Quitter, L = Laki-laki/Male and 3 = response sequence), data display through triangulation matrices and conclusion drawing. Stage 2 involved one Grade X class (n = 32) at SMAN 7 Makassar with in-depth observation of 3 representative students (1 per AQ category) for metapedadidactic analysis.

For the quantitative phase, the study employed a quasi-experimental design with pretest and posttest comparison groups. Participants included 80 Grade X students at SMAN 21 Makassar, a different school selected to minimise contamination effects from the qualitative phase. The experimental group (Class X-2, n = 40) received DDE-based instruction, whilst the control group (Class X-1, n = 40) received Problem-Based Learning (PBL)-based numeracy literacy instructtion over the same duration (8 meetings). Independent samples t-test on pretest scores confirmed group equivalence ($t(78) = 0.847$, $p = 0.399$, indicating no significant difference at $\alpha = 0.05$) and a chi-square test for AQ distribution confirmed comparable AQ profiles across groups ($\chi^2(2) = 0.156$, $p = 0.925$). The study assessed effectiveness through five indicators: Normalised Gain (N-Gain) measuring learning improvement from pretest to posttest (44), Cohen's d effect size quantifying the magnitude of group differences (45), classical completeness percentage reflecting the proportion of students meeting the Minimum Mastery Criteria threshold of 75, implementation fidelity measured through structured observation by two independent raters (46, 47) and student response questionnaire assessing perceived learning quality.

The study employed six instruments for data collection, each subjected to expert validation and reliability testing. The Learning Obstacles Test (18 items) received validation from five mathematics education experts, yielding a mean content validity score of 4.56/5.0. The ARP Questionnaire (36 items) demonstrated high internal consistency with Cronbach's $\alpha = 0.891$. The Numeracy Pretest and Posttest (30 items) achieved Pearson reliability of $r = 0.84$. The Implementation Fidelity Observation instrument (24 items) showed inter-observer reliability with Intraclass Correlation Coefficients (ICC) ranging from 0.540 to 0.747, where ICC represents the degree of agreement between two independent raters. The Student Response Questionnaire (20 items) demonstrated Cronbach's $\alpha = 0.876$. Expert review validated the semi-structured Interview Protocol (25 items). Table 4 presents detailed validity and reliability evidence for all instruments.

The study employed six instruments for data collection, each subjected to expert validation and reliability testing.

Table 4: Instrument Validity and Reliability Evidence

Instrument	Expert Validity	Reliability	Method	Items
Learning Obstacles Test	4.56/5.0	N/A	Content validity	18
ARP Questionnaire	4.72/5.0	α = 0.891	Cronbach's Alpha	36
Numeracy Pretest and Posttest	4.63/5.0	r = 0.84	Pearson	30
Implementation Fidelity Observation	4.48/5.0	ICC = 0.540 to 0.747	Inter-observer	24
Student Response Questionnaire	4.44/5.0	α = 0.876	Cronbach's Alpha	20
Interview Protocol (semi-structured)	4.52/5.0	N/A	Expert review	15

Table 4 provides comprehensive validity and reliability evidence for all six instruments employed in this study. Expert validity scores ranged from 4.44 to 4.72 out of 5.0 across all instruments, indicating consistently strong content and construct validity as evaluated by independent experts. Reliability coefficients were equally robust, with Cronbach's α values of 0.891 and 0.876 for the ARP and student response questionnaires respectively and inter-observer ICC values ranging from 0.540 to 0.747 for implementation fidelity. These psychometric properties confirm that the measurement framework meets established standards for educational research.

Results

Learning Obstacles Identification (RQ1)

The research team carried out learning obstacle identification through data triangulation involving in-depth interviews, analysis of student work artefacts in solving SLITV problems with applicative contexts and process observation. Six research participants representing three AQ categories participated, with their initial characteristics presented in Table 5.

Table 5 summarises the demographic and cognitive profiles of the six qualitative research participants, illustrating the purposive sampling strategy designed to capture maximum AQ variation. The ARP scores range from 48 (Quitter) to 142 (Climber), reflecting the full spectrum of adversity response profiles. Initial characteristics reveal a clear gradient: Quitters exhibited fundamental conceptual errors and inability to formulate systems, Campers demonstrated adequate but incomplete procedural understand-ding and Climbers displayed comprehensive analytical approaches. Gender balance within each AQ category further strengthened the represent-tational diversity of the qualitative sample.

Table 5: Research Subject Profiles

AQ	Code	Gender	ARP Score	Initial Characteristics
Quitter	QL	M	52	Incorrect system formulation; unable to draw graphs; many conceptual errors
Quitter	QP	F	48	Cannot formulate system; difficulty with verbal to mathematical translation
Camper	CL	M	108	Correct system; imprecise graphs; good procedural understanding
Camper	CP	F	112	Correct system; incomplete interpretation; systematic approach
Climber	CLM	M	138	Correct system; in-depth analysis; comprehensive approach
Climber	CLP	F	142	Correct system; complete interpretation; theoretical understanding

Regarding ontogenic-psychological obstacles, the Quitter group displayed severe psychological barriers characterised by three interrelated dimensions: mathematics anxiety, learned helplessness and fixed mindset. Coded interview data revealed pervasive emotional blockages that impeded cognitive engagement. Representative excerpts include: [QL3] "I feel like giving up from the start"; [QL4] "It's too complicated, I can't do it"; [QP1] "Anxious, Sir"; [QP3] "Afraid of not being able to do it." Learned helplessness manifested in permanent beliefs about inability: [QL7] "I indeed cannot do linear inequality systems"; [QP5] "Still can't, so I'm becoming less confident." In contrast, Camper participants exhibited qualitatively different psychological obstacles, not inability, but a self-imposed "good enough" mentality: [CL5] "I usually stop when I get an answer"; [CL8] "A score of 75 is enough"; [CP6] "If it's already correct, that's it, no need to think further." Notably, Campers demonstrated what this study terms an "unactualized growth mindset," an acknowled-gement of potential for development with a conscious choice not to pursue it: [CL12] "I can, but this is enough." Climbers showed a positive psychological profile with high intrinsic motiva-tion and growth mindset: [CLM1] "Very interesting, I'm challenged to solve it"; [CLP1] "Curious and want to prove that I can." Psychological obstacles proved largely absent for this group.

Concerning ontogenic-conceptual and procedural obstacles, Quitters' conceptual understanding remained superficial and restricted to keyword recognition without deep comprehension ([QL16] "Inequality uses greater than or less than signs"). Procedurally, Quitters could not perform basic algebraic manipulations: [QL22] "Don't know where to start"; [QP20] "Confused with the steps." Student work analysis confirmed systematic errors such as using '=' instead of '≤', inability to determine intercept points and failure to draw boundary lines. Campers demonstrated adequate conceptual understanding for standard applica-tions but lacked depth ([CL18] "Inequality is a constraint that doesn't have to be exact") and executed procedures competently yet without justification: [CL24] "I follow the steps that were taught." Climbers demonstrated deep structural and relational understanding: [CLM18] "Systems of inequalities define feasible regions, not single points"; [CLP20] "Each inequality divides the coordinate plane into two half-planes." The analysis noted proficiency with occasional rushing errors.

In terms of ontogenic-instrumental obstacles, Quitters could not translate between representa-tions (verbal to mathematical, mathematical to graphical): [QL30] "Cannot represent it in a graph";

[QP28] "Difficult to convert stories into inequalities." Campers could work within individual representations but had difficulty connecting them: [CL30] "Can draw graphs but connecting them with contextual answers is difficult." Climbers showed strong multi-representation use with seamless transitions. Regarding didactical obstacles, prior instruction for Quitters relied on procedural drilling without contextual meaning-making: [QL35] "Teacher directly gave formulas, told to memorise." Camper instruction favoured an exam-oriented approach, reinforcing minimum-standard satisfaction:[CL36] "Teacher focused on exam questions." For Climbers, the primary obstacle concerned curriculum limitations: [CLM36] "Classroom is not challenging enough, I learn on my own on YouTube." With respect to epistemological obstacles, Quitters encountered significant abstraction barriers: [QL40] "Don't understand why inequalities have many answers." Campers experienced region classification issues:[CL38] "Confused determining the feasible region." Climbers exhibited no significant epistemological obstacles. Table 6 presents a summary of all learning obstacles by AQ category with evidence codes.

Table 6: Summary of Learning Obstacles by AQ Category with Evidence Codes

Obstacle Type	Quitter (Severe)	Camper (Moderate)	Climber (Minimal)
Psychological	Anxiety, learned helplessness, fixed mindset [QL3,QL7,QP1,QP5]	Comfort-zone satisfaction; "good enough" mentality [CL5,CL8,CP6]	Minimal; high intrinsic motivation [CLM1,CLP1]
Conceptual	Superficial keyword recognition [QL16,QP15]	Adequate procedures without depth [CL18,CP16]	Strong but may skip justification [CLM18,CLP20]
Procedural	Cannot perform basic manipulations [QL22,QP20]	Competent for standard problems [CL24]	Proficient but may rush [CLM28]
Instrumental	Cannot translate representations [QL30,QP28]	Difficulty connecting representations [CL30]	Strong multi-representation use
Didactical	Procedural instruction issues [QL35,QP34]	Exam-oriented instruction [CL36,CP35]	Curriculum limitations [CLM36]
Epistemological	Abstraction barriers [QL40]	Region classification issues [CL38]	Not identified [CLM40: advanced understanding]

Table 6 synthesises the complete typology of learning obstacles across all three AQ categories, supported by specific evidence codes from interview transcripts, student work artefacts and classroom observations. A clear severity gradient emerges: Quitters experience severe manifestations across all six obstacle types, Campers display moderate obstacles primarily characterised by self-limiting behaviours rather than inability and Climbers exhibit minimal obstacles confined largely to curriculum limitations. This systematic mapping provides the empirical foundation for the differentiated scaffolding design, ensuring that each AQ profile receives targeted intervention aligned with its specific obstacle pattern.

A critical finding concerns the identification of an "obstacle cascade" mechanism in Quitters: psychological obstacles (LO-01) actively generated and sustained all other obstacles. Mathematics anxiety prevented cognitive engagement, which reinforced learned helplessness, which prevented skill acquisition, creating a self-reinforcing cycle. This finding extends the TDS framework (28) in which learning obstacles function as relatively independent categories.

Hypothetical Didactical Design (RQ2)

Drawing upon the identified learning barriers, the research team formulated a Hypothetical Didactical Design (DDH) by integrating TDS with a novel SCALE framework and AQ-responsive scaffolding. The DDH consists of four progressive Didactical Situations (SD1 - SD4) employing authentic contexts: SD1 (snack stall context for basic concepts), SD2 (photocopy business context for graphical representation), SD3 (event planning context for solution region classification) and SD4 (bakery optimisation context for integration). The SCALE framework extends classical dialectics with explicit phases, as Table 7 details.

Table 7: SCALE Framework Phases and Theoretical Grounding

SCALE Phase	Description	Brousseau Alignment	AQ Differentiation
Set up Goals	Establish didactical contract; activate prior knowledge through familiar contexts	Action situation	Familiar contexts reduce Quitter anxiety; challenge previews engage Climbers
Contradict Adidactic	Differentiated exploration with cognitive conflict through worksheets	Action + Formulation	Procedural scaffolding (Quitters); Metacognitive scaffolding (Campers); Strategic scaffolding (Climbers)
Anonymous Gallery	Democratic peer review with psychological safety; anonymous work display	Validation (extended)	Psychological safety for Quitters; peer teaching for Campers; critical evaluation for Climbers
Lock-In	Systematic institutionalisation through Quitter, Camper, Climber sequencing	Institutionalisation	Inclusive formalisation respecting diverse entry points
Evaluate/Extended	Transfer, metacognitive reflection and extension challenges	Transfer phase	Consolidation (Quitters); Exploration (Campers); Generalisation (Climbers)

Table 7 details the five phases of the SCALE framework and their alignment with both Brousseau dialectical situations and AQ-differentiated instruction. Each phase serves a distinct pedagogical function: Set up Goals reduces anxiety through familiar contexts, Contradict Adidactic provides differentiated cognitive challenges, Anonymous Gallery establishes psychological safety for peer evaluation, Lock-In ensures inclusive institutionalisation and Evaluate/Extended promotes transfer across ability levels. The explicit mapping between theoretical alignment and AQ differentiation demonstrates how the framework translates abstract theoretical principles into concrete, implementable teaching sequences.

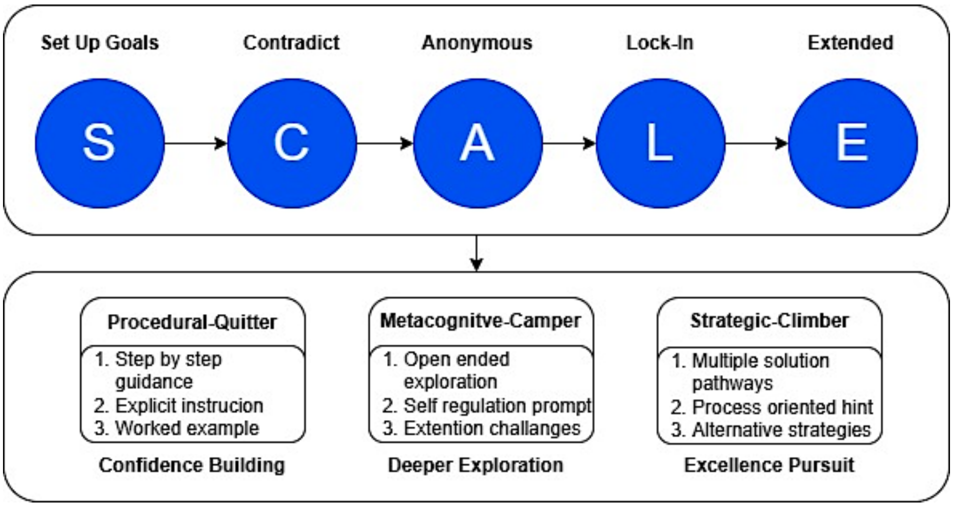

Figure 3: SCALE Framework with Differentiated Scaffolding

The research team differentiated three scaffolding types through worksheets with varying levels of interaction and intervention support. Procedural scaffolding (primarily for Quitters) provides step-by-step guidance and high structure to reduce anxiety whilst building foundational skills. Metacognitive scaffolding (primarily for Campers) presents open-ended exploration and self-monitoring prompts to promote deeper exploration beyond minimum requirements. Strategic scaffolding (primarily for Climbers) offers multiple solution pathways and explicit encouragement to pursue excellence. Expert validation yielded mean scores of 4.52/5.0 for content validity, 4.48/5.0 for construct validity and 4.61/5.0 for pedagogical appropriateness. Figure 3 illustrates the SCALE framework with its differentiated scaffolding structure. This figure provides a visual representation of the SCALE framework architecture, depicting the relationships among the five phases and the three tiers of differentiated scaffolding. The figure illustrates how procedural scaffolding (for Quitters), metacognitive scaffolding (for Campers) and strategic scaffolding (for Climbers) operate in parallel within each SCALE phase, ensuring that all students engage with the same mathematical content whilst receiving support calibrated to their specific AQ profiles. The visual layout clarifies the simultaneous operation of vertical progression (across phases) and horizontal differentiation (across AQ profiles).

Metapedadidactic Implementation and Empirical Didactical Design (RQ3)

The research team implemented the DDH across four Didactical Situations (SD1 - SD4) with one Grade X class (n = 32) at SMAN 7 Makassar. Metapedadidactic analysis examined teacher, student and content interactions through the SCALE framework phases, documenting how AQ-responsive scaffolding addressed learning obstacles. Three representative students participated in in-depth observation: MZ (Quitter), NF (Camper) and F (Climber).

Procedural scaffolding through worked examples and structured checklists facilitated MZ's (Quitter) transition from avoidance behaviour to active participation. In SD1 (Set up Goals phase), coded observation [OBS-00:04] recorded MZ as initially passive and silent. Using the familiar snack-stall context, [TRN-SU-18] MZ stated: "One must be exact, one can be less," demonstrating initial conceptual awareness. During the Contradict Adidactic phase, the three-stage scaffolding strategy (worked example, guided practice, independent practice) proved effective: [OBS-00:18] MZ read the worked example carefully; [ART-MZ-CT-01] margin note: "Must be positive integers." By independent practice [OBS-00:44] MZ worked independently with confidence. The Anonymous Gallery phase created psychological safety: [WWC-MZ] "I felt more relaxed because no one knew whose work it was." By SD4, MZ independently developed visual mnemonics using three-colour highlighters (green = bounded, blue = unbounded, red = empty) for solution region classification, a student-generated innovation later formalised in the DDE.

Metacognitive scaffolding through metacognitive questioning triggered critical reflection in NF (Camper). In SD1, NF demonstrated procedural competence but without justification [ART-NF-EJ-01 - EJ-04]; procedures were correct but notes purely descriptive. The teacher's metacognitive intervention [OBS-00:25] "Why only 2?" triggered a reflective pause averaging 8 seconds [TRN-CT-C-09 to C-15] before NF revised notes with justification. By SD3, NF had internalised the justification habit: [WWC-P-C-16] "Automatically write BECAUSE without being asked." The 4-Step Protocol (Solve, Identify boundary type, Check with test point, Determine region classification) emerged during SD3 as particularly effective for Campers, providing structured metacognitive checkpoints that prevented premature stopping whilst maintaining student autonomy. The team subsequently formalised this protocol in the DDE.

Strategic scaffolding through parameter sensitivity analysis and problem posing maintained engagement for F (Climber). In SD1, F completed basic exercises in 5 minutes [OBS-00:18], necessitating extension questions for deep exploration. Through Desmos exploration in SD4, F independently developed the "binding constraint" concept: [CLM44] "Binding constraint is the constraint that determines the boundary of the best solution region." Further generalisation of classification criteria followed: [CLM40] "Even for n variables, the principle remains the same: check constraint consistency," demonstrating how open-ended scaffolding facilitated advanced conceptual development beyond curriculum expectations.

The fading principle received empirical validation across the four didactical situations. MZ (Quitter) progressed from complete passivity in SD1 - independent development of the three-colour highlighter system in SD4. NF (Camper) transitioned from purely descriptive note-taking in SD1 - self-initiated exploration of alternative solution methods in SD4. F (Climber) moved from rapid exercise completion in SD1 - autonomous development of the binding constraint concept and n-variable generalisation in SD4. This progressive trajectory across all three profiles confirms that the research team appropriately calibrated scaffolding fading to each AQ profile's zone of proximal development. Figure 4 depicts the implementation and retrospective analysis process.

Figure 4 depicts the cyclical process of implementation and retrospective analysis conducted during the metapedadidactic phase. The diagram shows how classroom observations, student work artefact analysis and coded transcripts from each Didactical Situation (SD1 through SD4) fed into a continuous refinement loop. Unanticipated student responses—such as MZ's three-colour highlighter innovation and NF's emergence of the 4-Step Protocol—were systematically documented, analysed and subsequently formalised in the Empirical Didactical Design, demonstrating the iterative and responsive nature of the DDR methodology.

Retrospective analysis identified components requiring refinement. Most DDH components proved effective (4 Didactical Situations, SCALE phases, 3 scaffolding types, authentic contexts, fading principle). Table 8 synthesises the substantive revisions from DDH to DDE.

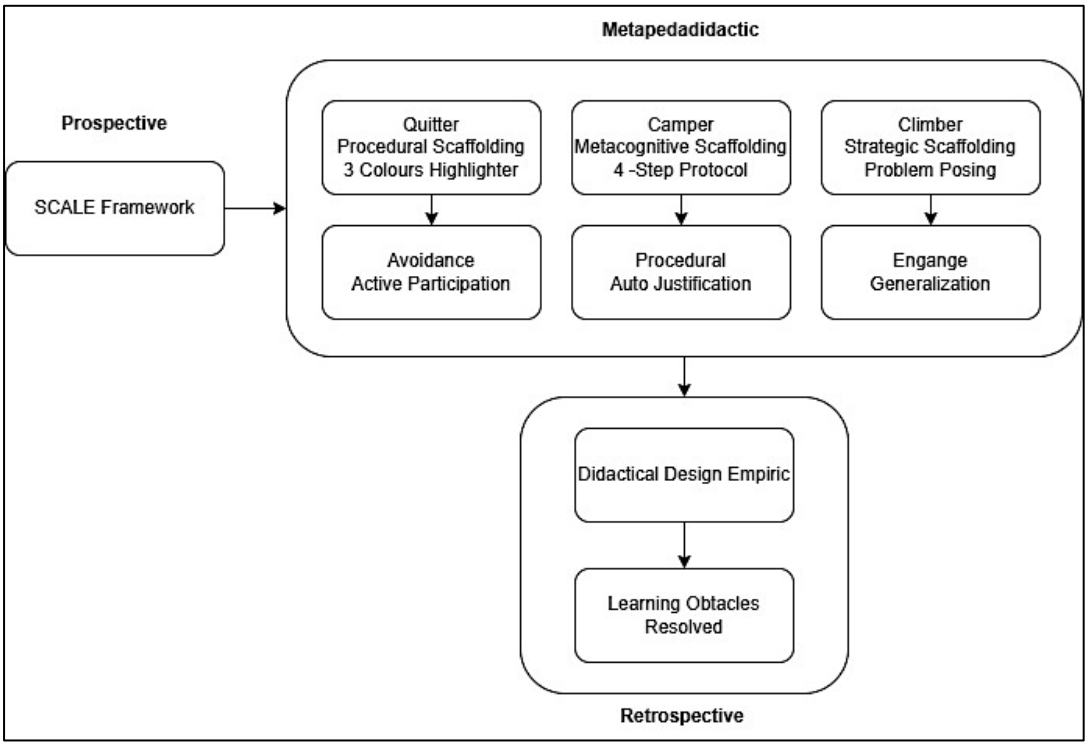

Figure 4: Implementation and Retrospective Analysis Process

Table 8: Synthesis of DDH to DDE Revisions

Aspect	DDH	DDE Revision (Empirical Basis)
Didactical-Pedagogical Anticipations	Theoretical predictions	+16 new ADP based on actual responses (e.g., Quitters requesting second example before trying; Campers finishing without exploring patterns)
Visual Aids: Colour Coding	Not specified	Formalised: Green (valid), Red (invalid) for graphical regions; Three-colour highlighter system
4-Step Protocol	Not present	Formalised for Campers in SD3: Solve, Identify, Check, Determine (emerged from NF's successful transition)
"Table as Bridge" Strategy	Implicit	Explicit bridging strategy: Context, Table, Graph, Interpretation
Technology Integration	Optional	Explicit Desmos guide for Climber SD4 (based on F's successful discovery learning)
Peer Teaching Structure	Unstructured	Structured within Anonymous Gallery (spontaneous peer teaching proved highly effective)
Productive Struggle	Not present	Explicit productive struggle design for SD4 discovery-based optimisation

Table 8 presents the seven substantive revisions that transformed the Hypothetical Didactical Design into the Empirical Didactical Design, each grounded in specific classroom evidence. The most significant additions include 16 new Didactical-Pedagogical Anticipations derived from actual student responses, the formalisation of visual aids and colour-coding systems that emerged spontaneously from student practice and the structured 4-Step Protocol for Campers. These revisions demonstrate that the DDR methodology successfully captures the complexity of real classroom interactions and transforms emergent student innovations into reproducible instructional components.

DDE Effectiveness Evaluation (RQ4)

The research team evaluated the validated DDE through a quasi-experimental design at SMAN 21 Makassar involving 80 Grade X students. Independent samples t-test on pretest scores ($t(78) = 0.847$, $p = 0.399$) and chi-square test for AQ distribution ($\chi^2(2) = 0.156$, $p = 0.925$) confirmed group equivalence. Table 9 presents the N-Gain descriptive statistics, where N-Gain represents the ratio of actual gain to maximum possible gain, with values above 0.70 classified as "High" and values between 0.30 and 0.70 classified as "Medium" (44).

Table 9 presents the N-Gain descriptive statistics, revealing a substantial difference between the experimental group (mean = 0.8225, classified as High) and the control group (mean = 0.6740, classified as Medium). Notably, the experimental group's reduced standard deviation (0.0796 versus 0.0937) suggests that the AQ-responsive differentiated scaffolding not only elevated overall performance but also produced more uniform gains across diverse learner profiles. The minimum N-Gain of 0.64 in the experimental group, compared to 0.47 in the control group, further indicates that even the lowest-performing students in the DDE condition achieved meaningful learning improvements.

Table 9: Descriptive Statistics of N-Gain Scores

Group	N	Mean	SD	Min	Max	Category
Experimental (DDE)	40	0.8225	0.0796	0.64	1.00	**High**
Control (PBL)	40	0.6740	0.0937	0.47	0.79	Medium

Independent samples t-test confirmed statistical significance: $t(78) = 7.542$, $p < 0.001$, with a mean difference of 0.1485 (22.0% improvement). Effect size analysis using Cohen's d yielded d = 1.687, classified as "Very Large Effect" (45), substantially exceeding the 0.80 benchmark. In this context, Cohen's d represents the standardised difference between experimental and control group means divided by the pooled standard deviation (SD), where SD denotes the standard deviation measuring score dispersion within each group. The reduced SD in the experimental group (0.0796 versus 0.0937) indicates that the differentiated scaffolding successfully accommodated student heterogeneity, producing more equitable gains across diverse learner profiles. Table 10 presents the comprehensive multi-indicator effectiveness summary.

Table 10: Comprehensive Multi-indicator Effectiveness Summary

Indicator	Experimental (DDE)	Control (PBL)	Statistical Test
N-Gain Mean	0.8225 (High)	0.6740 (Medium)	t = 7.542, p < 0.001
Cohen's d	1.687 (Very Large)		
Classical Completeness	85% (Achieved)	65% (Not achieved)	z = 2.066, p = 0.039
Implementation Fidelity	97% (Very Good)	90.75%	t = 2.186, p = 0.046
Student Response	95.91% (Very Positive)	78.16% (Positive)	t = 34.288, p < 0.001
Fidelity Progression	P1 (90.5%) to P7 (100%)	P1 (87%) to P7 (95%)	Positive learning curve
Response Progression	P1 (88.44%) to P7 (99.75%)	P1 (75%) to P7 (82%)	Consistent positive trend
Hypothesis Testing	All 4 null hypotheses rejected		Convergent validity confirmed

Table 10 consolidates all effectiveness indicators into a comprehensive multi-dimensional evaluation, demonstrating convergent validity across quantitative metrics. All four null hypotheses were rejected at statistically significant levels, with Cohen's d = 1.687 representing a very large effect size that substantially exceeds conventional benchmarks. The progressive improvement in both implementation fidelity (from 90.5% in first meeting to 100% in seventh meeting) and student responses (from 88.44% to 99.75%) indicates positive learning curves for both the teacher and students, suggesting that the DDE becomes increasingly effective with sustained implementation.

Discussion

The detection of six distinct learning obstacle types exhibiting qualitatively different manifestations across AQ profiles constitutes a meaningful advance in didactical design theory. The pronounced mathematics anxiety, learned helplessness manifestations and fixed mindset observed among Quitter students align with meta-analytic evidence demonstrating consistent negative associations between mathematics anxiety and achievement (48). This finding extends comprehensive reviews indicating that highly mathematics-anxious students adopt maladaptive learning strategies, including diminished effort investment, inefficient learning environment organisation and reduced concentration during learning activities (49-51). Furthermore, research on emotion regulation in mathematics anxiety demonstrates that cognitive reappraisal strategies moderate the anxiety and performance relationship (52), a finding consistent with the effectiveness of the Anonymous Gallery phase in reducing Quitter anxiety through environmental restructuring rather than individual coping demands.

The most theoretically noteworthy finding is the "obstacle cascade" mechanism identified among Quitters: psychological obstacles (LO-01) actively produce and perpetuate all other obstacles through a self-sustaining cycle. Mathematics anxiety blocks cognitive engagement, which strengthens learned helplessness, which in turn prevents effort and skill development. This extends the TDS framework (31, 32, 34) wherein learning obstacles function as relatively independent categories. The evidence suggests that for students with low adversity quotient, psychological obstacles operate as "root obstacles" necessitating intervention before or concurrently with cognitive and procedural approaches. This framework introduces AQ as a moderator of regulation strategy effectiveness, complementing recent evidence on the interplay between non-cognitive factors and mathematical reasoning (53, 54). Additional research confirms that metacognitive awareness mediates the relationship between affective factors and mathematics performance, reinforcing the theoretical basis for addressing psychological obstacles as precursors to cognitive development (55, 56).

The Camper group's "unactualized growth mindset" represents a particularly novel contribution. Whereas the growth mindset framework (55) typically positions growth beliefs as directly predictive of achievement-oriented behaviours, the coded evidence [CL12: "I can, but this is enough"] illustrates that believing in developmental potential does not automatically translate into proactive learning behaviour. This addresses a gap in the literature that has generally treated growth mindset as a unitary construct, consistent with recent critiques suggesting that mindset effects exhibit greater contextual dependence than originally proposed (56). Moreover, the pragmatic motivational orientation observed among Campers diverges from longitudinal findings suggesting that achievement predicts intrinsic motivation (57), indicating that the motivation and achievement relationship is moderated by personal standards and goal orientation. Recent studies on motivational regulation in mathematics further support this finding, demonstrating that self-set performance thresholds mediate the relationship between motivational beliefs and academic effort (58). The Climber group's advanced epistemological understanding and independent development of binding constraint concepts confirm the characterisation of Climbers as persistent excellence pursuers (17). The sole didactical obstacle (curriculum limitations) and compensatory self-directed learning support theoretical perspectives on intrinsic motivation's role in deeper processing and stronger persistence (57, 59).

The synthesis of TDS, Vygotsky's ZPD and AQ framework into the SCALE pedagogical model constitutes a novel theoretical integration. Metapedadidactic evidence demonstrates the framework's differential effectiveness: for Quitters, the Set up Goals phase with familiar contexts reduced initial anxiety, whilst the Anonymous Gallery established psychological safety essential for participation. For Campers, metacognitive questioning ("Why?") during the Contradict Adidactic phase triggered the critical transition from procedural to conceptual understanding, with the 8-second reflective pause suggesting genuine conceptual restructuring rather than surface compliance. This finding aligns with research on productive failure indicating that carefully structured struggle promotes deeper learning than direct instruction alone (60). For Climbers, the Evaluate/Extended phase sustained engagement through parameter sensitivity analysis and problem posing leading to conceptual development that transcended curricular expectations, consistent with evidence on the role of open-ended tasks in supporting mathematically gifted students (61).

The empirical emergence of student-generated innovations during implementation, particularly the three-colour highlighter system, the 4-Step Protocol and the binding constraint concept, validates the devolution principle: when appropriately scaffolded, students construct knowledge that sometimes surpasses pedagogical expectations (31). The research team formalised these innovations in the DDE through retrospecttive analysis, demonstrating the iterative refinement power of the DDR methodology (10, 32). The addition of 16 new Didactical-Pedagogical Anticipations based on unanticipated student responses ensures that the DDE captures the complexity of authentic classroom implementation. This finding is consistent with design-based research principles emphasising that iterative refinement through classroom enactment produces more robust designs than purely theoretical development (62).

The aggregate effect magnitude (d = 1.687) substantially exceeds outcomes documented in comparable intervention studies. A scaffolding meta-analysis yielded a mean g of 0.776 (13), a meta-analysis of didactical interventions reported a mean d of 0.54 (63), the threshold for meaningful educational interventions stands at d = 0.40 (64) and computer-based scaffolding meta-analyses have reported effects ranging from d = 0.34 to d = 0.63 depending on implementation context (16). The present effect size markedly surpasses all these benchmarks. Employing the Common Language Effect Size interpretation (65), d = 1.687 indicates that a randomly selected student from the experimental group has approximately 88% probability of scoring higher than a randomly selected control student, an effect equivalent to more than 1.5 standard deviations of academic growth.

The reduced standard deviation in the experimental group (0.0796 versus 0.0937) reveals a pattern termed "equitable acceleration": the AQ-responsive differentiation simultaneously benefits all learner types without zero-sum tradeoffs between equity and excellence. This aligns with differentiated instruction principles (66) and extends them with an empirical mechanism, namely AQ-calibrated scaffolding delivered through differentiated worksheets. The 85% classical completeness (34 of 40 students meeting the threshold of 75), significantly higher than the control group's 65% (26 of 40), indicates that 8 additional students per class of 40 achieve minimum competency, a practically meaningful difference for educational policy.

The convergence of all four effectiveness indicators provides robust triangulated evidence. The progression of implementation fidelity from P1 (90.5%) to P7 (100%) and student response from P1 (88.44%) to P7 (99.75%) demonstrates positive learning curves for both teachers and students, consistent with mastery experience theory (67) and teacher professional development research (68). Several alternative explanations for the effect size warrant consideration. The research team specifically designed the DDE to target identified learning obstacles, whereas the PBL control followed a general numeracy literacy approach. Both groups received instruction of comparable duration (8 meetings) from the same teacher, mitigating teacher-effect confounds. Novelty and Hawthorne effects cannot be entirely excluded, though the progressive increase in student response from P1 - P7 argues against a novelty-driven explanation. Whilst these considerations support the validity of the findings, replication studies with randomised assignment and multiple school sites remain necessary to establish external validity.

This study provides four primary theoretical contributions: (a) empirical evidence for integrating didactical theory, socio-cultural theory and individual difference theory within a coherent numeracy learning framework; (b) the "obstacle cascade" model extending the TDS framework by demonstrating that psychological obstacles in low-AQ students actively generate and maintain other obstacle types; (c) validation of AQ-differentiated scaffolding as an effective strategy for accommodating student heterogeneity in mathematics education; and (d) the SCALE framework as an actionable pedagogical model translating theoretical synthesis into implementable teaching sequences.

For practitioners, several actionable recommend-dations emerge. First, systematic AQ profile assessment should complement cognitive readi-ness assessment as a basis for scaffolding differentiation; the ARP instrument employed in this study can be administered within a single class period. Second, three-tiered scaffolding through differentiated worksheets calibrated to AQ profiles effectively serves diverse learners; teachers should prepare parallel worksheet versions at procedural, metacognitive and strategic levels. Third, teachers should incorporate Anonymous Gallery or similar psychological safety mechanisms to create conditions where anxiety-prone students can participate without fear of judgement. Fourth, the obstacle cascade phenomenon requires addressing psychological barriers as prerequisites to effective cognitive intervention; classroom warm-up activities using familiar contexts serve this purpose. Fifth, teachers should employ authentic progressive contexts to build numeracy competencies whilst maintaining student engagement across all AQ profiles.

Conclusion

This study developed a numeracy didactical design comprising four progressive didactical situations using the SCALE framework that integrates three-tiered differentiated scaffolded instruction delivered through worksheets with varying interaction and intervention support: procedural for Quitters, metacognitive for Campers and strategic for Climbers. The qualitative phase identified six types of learning obstacles with distinct manifestations across AQ profiles, with coded evidence from interview transcripts, student work artefacts and observation documenting an "obstacle cascade" mechanism in Quitters where psychological ontogenic obstacles serve as root causes, the "good enough" mentality as a self-imposed limiting factor in Campers and curriculum limitations as the sole obstacle in Climbers.

The DDH, grounded in TDS and AQ-responsive scaffolding, underwent iterative refinement through metapedadidactic analysis across four didactical situations. Retrospective analysis yielded the DDE with substantive revisions including 16 new Didactical-Pedagogical Anticipations, formalised visual aids, the 4-Step Protocol for Campers and structured peer teaching within Anonymous Gallery. The DDE demonstrated very high effectiveness: Cohen's d = 1.687 (very large effect), experimental N-Gain of 0.82 (high category) versus control of 0.67 (medium category), classical completeness at 85%, imple-mentation fidelity of 97% and student responses at 95.91% (very positive). The "equitable acceleration" pattern confirms that well-designed AQ-differentiated scaffolding can serve all learners without zero-sum tradeoffs between equity and excellence.

Limitations

Several limitations require acknowledgement. First, the quasi-experimental design, whilst strengthened by pretest equivalence testing and AQ distribution matching, cannot fully control for school-level variables or unmeasured confounds between the two school sites; differences in school culture, teacher and student relationships and institutional resources may have influenced outcomes beyond the measured variables. Second, the study focused specifically on systems of linear inequalities within the Indonesian senior second-dary curriculum; generalisability to other mathematical domains (e.g., calculus, statistics, geometry) or educational contexts (e.g., primary education, higher education) requires further investigation. Third, longer-term retention and far-transfer effects remain unmeasured, as the posttest was administered immediately after the intervention; it remains unknown whether the observed gains persist over weeks or months or transfer to novel mathematical contexts. Fourth, the single-country, single-city context limits cross-cultural generalisability, particularly given that AQ manifestations may differ across cultural contexts with varying educational traditions and attitudes toward mathematics. Fifth, AQ categorisation relied on fixed-score boundaries (17), which may not account for cultural variations in adversity response or for AQ as a potentially dynamic rather than static trait. Sixth, the relatively small sample (n = 80 for the quasi-experiment; n = 6 for qualitative obstacle identification) limits statistical power for subgroup analyses by AQ category and restricts the transferability of qualitative findings. Seventh, whilst implementation fidelity reached

97%, the presence of the researcher during instruction may have introduced observer effects that would not be present in routine classroom practice.

Future Perspectives

Several promising directions for future research emerge from this study. Longitudinal studies tracking AQ development alongside mathematical achievement over one or more academic years would clarify whether the observed gains persist and whether the intervention produces lasting changes in AQ profiles themselves. Technology-enhanced implementations using adaptive learning systems could enable real-time AQ-responsive scaffolding calibration, automatically adjusting support levels based on student performance and engagement indicators. Cross-cultural validation across ASEAN and OECD contexts would establish the generalisability of the obstacle cascade model and the SCALE framework across diverse educational systems. Investigation of teacher professional development requirements for implementing AQ-differentiated instruction would inform scalability considerations, as the current study relied on researcher-led implementation. Multi-factor designs examining AQ interactions with prior knowledge, learning disabilities and socioeconomic factors would provide a more comprehensive understanding of individual difference variables affecting numeracy learning. Additionally, replication studies with randomised assignment at multiple school sites would strengthen causal claims. Finally, extending the SCALE framework to other mathematical domains and grade levels would test the boundary conditions of the present findings.

Abbreviations

AQ: Adversity Quotient, DDE: Empirical Didactical Design, DDH: Hypothetical Didactical Design, DDR: Didactical Design Research, N-Gain: Normalised Gain, OECD: Organisation for Economic Co-operation and Development, PISA: Programme for International Student Assessment, SCALE: Set up Goals, Contradict Adidactic, Anonymous Gallery, Lock-In, Evaluate/Extended, SLITV: Systems of Linear Inequalities in Two Variables, TDS: Theory of Didactical Situations.

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Author Contributions

Fahruh Juhaevah: research conceptualisation, methodological design, fieldwork, data analysis, manuscript drafting, critical revision, Hamzah Upu: research conceptualisation, supervision, validation, critical revision, Bernard: methodological design, validation, critical revision, Ahmad Talib: resource provision, validation, critical revision. Each author endorsed the submitted version, assumes accountability for the entirety of the work and shares collective responsibility for ensuring its scholarly rigour.

Conflict of Interest

The authors confirm that no competing interests exist in relation to the publication of this work.

Data Availability

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

Declaration of Artificial Intelligence (AI) Assistance

During the preparation of this manuscript, the authors used AI-based tools exclusively for linguistic polishing and grammatical correction, with full oversight by the authors. The intellectual substance, datasets and analytical outcomes were entirely generated and validated by the research team.

Ethics Approval

The Research Ethics Committee of Universitas Negeri Makassar granted ethical clearance (Reference: UNM/REK/2025/0842). The research team secured written informed consent from every participant prior to data collection.

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