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Real-Life Contextualized Mathematics Problems and Multidimensional Problem-Solving Competence in High School Students: A Quasi-Experimental Investigation with Moderation Analysis

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ABSTRACT

This study investigates whether systematic integration of real-life contextualized mathematics problems over a full academic semester significantly improves Grade 10 students' multidimensional problem-solving competence compared to conventional procedural instruction. A quasi-experimental design with intact classrooms was employed across urban and semi-urban secondary schools. Problem-solving was operationalized as a five-component composite—contextual comprehension, mathematical modeling accuracy, strategy execution, representational fluency, and reflective validation—measured by a validated Problem-Solving Index (PSI). Moderation analyses examined whether teacher scaffolding quality and student reading comprehension influenced the relationship between instructional condition and PSI outcomes. Multilevel modeling (MLM) and Analysis of Covariance (ANCOVA) were applied to account for classroom clustering and pre-existing differences. Findings indicate that students receiving contextualized instruction achieved significantly greater gains on overall PSI scores, mathematical modeling accuracy, and representational fluency. Teacher scaffolding quality significantly moderated these effects, amplifying gains in high-scaffolding classrooms. Reading comprehension emerged as a significant moderator for modeling accuracy but not for strategy execution. Results have implications for curriculum reform, teacher professional development, and assessment design in secondary mathematics education.

Keywords: *Real-Life Contextualization, Mathematical Modeling, Problem-Solving Competence, Representational Fluency, Teacher Scaffolding, Multilevel Modeling, Quasi-Experimental Design, Secondary Mathematics.*

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JEL/Subject Classification: Mathematics Education, Instructional Design, Cognitive Development, Secondary Schooling.

1. INTRODUCTION

Secondary mathematics education has long been dominated by procedural instruction—training students to execute algorithms, manipulate algebraic expressions, and apply geometric theorems with accuracy. While such procedural proficiency is necessary, decades of empirical evidence and international assessment results consistently reveal a deep procedural–application gap: students who demonstrate competence on routine textbook exercises frequently struggle to interpret, model, and reason through problems embedded in real-world contexts (Niss and Blum, 2020; Schoenfeld, 2022). International frameworks for mathematical literacy, including PISA, now define competence in broader terms that encompass reasoning, representation, and validation in authentic situational contexts (Kappassova et al., 2025; Almarashdi and Jarrah, 2023).

Contextualized mathematics instruction responds to this gap by situating mathematical ideas within meaningful, familiar real-world scenarios—economic decision-making, ecological analysis, geometric design—thereby providing students with authentic contexts for developing and exercising mathematical reasoning (Chavarría-Arroyo and Albanese, 2023; Ferede et al., 2025). Unlike traditional word problems that simply apply a known algorithm to a verbal scenario, authentic contextualized problems require students to identify relevant variables, construct mathematical representations, execute reasoning processes, and validate their solutions against the original situation—a cyclical process formalized in mathematical modeling theory (Greefrath et al., 2023; Krawitz et al., 2025).

Despite a growing body of evidence supporting contextualized instruction, significant methodological and conceptual gaps persist in the existing literature. Most studies rely on aggregate achievement scores that obscure the multi-component structure of problem-solving; few disaggregate outcomes into theoretically founded dimensions. Short intervention durations (typically a few weeks) limit conclusions about sustained cognitive development. Classroom-level variation—particularly the moderating role of teacher scaffolding—is rarely examined through multilevel methods. And the contribution of students' reading comprehension to modeling performance is largely overlooked, despite its theoretical salience (Stephany, 2021; Goc-Ong and Doronio, 2025).

This study addresses these gaps through a semester-long (16-week) quasi-experimental investigation of Grade 10 students across urban and semi-urban secondary schools. The study pursues four objectives: (i) to examine the impact of contextualized mathematics instruction on students' overall problem-solving competence within a multidimensional framework; (ii) to assess improvements in mathematical modeling ability; (iii) to evaluate growth in representational fluency; and (iv) to analyze student engagement and determine the moderating role of teacher scaffolding. In doing so, it advances mathematical modeling theory, Realistic Mathematics Education (RME), and representational fluency theory while offering evidence-based recommendations for curriculum design, teacher training, and assessment reform.

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2. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

2.1 Mathematical Modeling Theory and the Problem-Solving Cycle

Mathematical modeling theory conceptualizes problem-solving as a cyclical, iterative process originating in the real world and returning to it for validation (Niss and Blum, 2020; Greefrath et al., 2022). The modeling cycle begins with comprehension of a real-world situation, proceeds through simplification and mathematical formulation, involves symbolic manipulation and solution derivation, and concludes with interpretation and validation of results against the original context (Geiger et al., 2022; Kohen, 2025). When the derived solution fails to satisfy real-world expectations, the model is revised and the cycle repeated.

This iterative, non-linear structure distinguishes authentic modeling tasks from routine procedural exercises. Students engaged in modeling must coordinate reasoning across multiple phases simultaneously, deploying judgment and metacognitive evaluation rather than algorithmic execution (Cevikbas et al., 2022). Empirical research confirms that modeling competencies develop progressively through sustained engagement with contextual tasks, not from isolated or short-term exposure (Vogelsanger-Holenstein et al., 2025; Hidayat et al., 2022).

2.2 Realistic Mathematics Education

Realistic Mathematics Education (RME), developed in the Netherlands, provides the pedagogical framework for this study's intervention design. RME emphasizes guided reinvention—students construct formal mathematical knowledge through structured engagement with contextually grounded tasks rather than receiving it through direct transmission (Van Den Heuvel-Panhuizen and Drijvers, 2020). Real-world contexts serve as starting points for mathematical concept development, supporting students' progression from informal problem-solving strategies to progressively abstract mathematical representations.

A robust and growing evidence base supports RME's effectiveness for developing mathematical problem-solving, literacy, and conceptual understanding across educational levels (Ventistas et al., 2025; Indiyarti Putri et al., 2025; Amidi et al., 2025). RME aligns with mathematical modeling theory in its emphasis on context as a resource for reasoning rather than a superficial wrapper for procedural tasks.

2.3 Representational Fluency

Representational fluency—the ability to move meaningfully between symbolic, graphical, tabular, and verbal representations of mathematical relationships—is both an outcome of and a resource for contextualized problem-solving (Fonger, 2019; Lajos, 2021). Fluency in representation is not merely the ability to produce multiple forms but involves dynamic coordination: using representations strategically and translating between them as the demands of a problem change (Biccard, 2025; Weingarden et al., 2026).

Research demonstrates that students exposed to rich contextual tasks develop greater representational flexibility than those receiving procedural instruction, as authentic problems require students to construct representations from situation semantics rather than retrieve them from memory (Fonger, 2019; Tupamahu et al., 2023). The present study operationalizes representational fluency as a scored index tracking both the probability and accuracy of cross-representational transitions across five task types.

2.4 Teacher Scaffolding as a Moderator

Scaffolding—the contingent instructional support provided by teachers through questioning, prompting, and feedback—is theorized to modulate the effectiveness of complex instructional tasks (Shin et al., 2020; Çakmak Gürel, 2025). In the context of modeling tasks, effective scaffolding maintains cognitive demand while guiding students through the interpretive challenges of situational problem-solving, reducing affective barriers without simplifying the mathematical reasoning required.

However, the relationship between scaffolding quality and student outcomes in contextualized mathematics is under-researched. While qualitative studies describe scaffolding strategies used during modeling (Teixeira et al., 2025), few quantitative studies examine scaffolding as a moderator of instructional effectiveness using multilevel methods. This study fills that gap through systematic observation of scaffolding quality and its interaction with the instructional condition.

2.5 Reading Comprehension and Mathematical Problem-Solving

Contextual mathematics problems require students to read and interpret extended narrative descriptions before constructing mathematical models. Students with limited reading comprehension may fail to extract quantitative relationships from problem texts, regardless of their mathematical capability (Stephany, 2021; Goc-Ong and Doronio, 2025). This language-mathematics interface is particularly salient for students in multilingual or diverse sociolinguistic contexts.

Despite this theoretical importance, reading comprehension is rarely included as a variable in mathematics education research on contextualized instruction. The present study examines reading comprehension as a moderator of the instruction-modeling accuracy relationship, providing a more ecologically valid account of the conditions under which contextualization is effective.

2.6 Research Gaps

The existing literature on contextualized mathematics instruction is limited by: (a) reliance on aggregate achievement scores that obscure multi-component problem-solving processes; (b) short intervention durations insufficient to document cognitive restructuring; (c) failure to account for classroom-level clustering through multilevel methods; (d) limited examination of teacher scaffolding as a moderator; and (e) neglect of student reading comprehension as a relevant covariate. This study addresses all five gaps within a coherent quasi-experimental framework.

3. RESEARCH METHODOLOGY

3.1 Research Design

A quasi-experimental pretest–posttest design with non-equivalent control groups was employed. Intact Grade 10 mathematics classrooms were assigned to either a contextualized instruction condition (treatment) or a conventional procedural instruction condition (control) within their respective schools. Assignment was made at the classroom level to preserve the natural instructional ecology. The 16-week intervention spanned one complete academic semester, encompassing units in algebra, geometry, and statistics.

The quasi-experimental design was selected to maximize ecological validity: findings reflect what can be achieved within normal school schedules, existing teacher–student configurations, and standard curriculum requirements. ANCOVA and multilevel modeling were employed to statistically control for baseline differences and classroom clustering, respectively, partially compensating for the absence of random assignment.

3.2 Participants and Sampling

Participants were Grade 10 students enrolled in urban and semi-urban secondary schools. A stratified sampling approach was used to select schools with comparable curriculum frameworks, infrastructure, and student demographic profiles. Intact classrooms within selected schools were assigned to conditions based on school-level logistics. Exclusion criteria eliminated rural schools and specialized institutions where structural resource disparities would confound intervention implementation.

Pre-intervention equivalence between conditions was verified on prior mathematics achievement (standardized scores), reading comprehension (validated instrument), and teacher experience. Parental consent and student assent were obtained in accordance with institutional ethical review requirements.

3.3 Intervention Design

The treatment condition received 16 weeks of contextualized mathematics instruction integrated into the standard Grade 10 curriculum. Contextualized problems were operationally defined as tasks with: (a) authentic situational framing aligned with adolescents' lived experiences; (b) explicit requirement for mathematical model construction; (c) structured opportunities for representational coordination; and (d) a concluding validation phase requiring students to assess solution reasonableness. Tasks were developed across algebra (growth and decay), geometry (spatial design problems), and statistics (real-data interpretation) to ensure cross-unit contextual diversity.

Teacher professional development (two pre-intervention workshops and bi-weekly reflection meetings) ensured consistent implementation of contextualized task design and scaffolding protocols. The control condition received instruction aligned with the same curriculum objectives using conventional procedural methods: direct instruction, worked examples, and algorithmic practice exercises.

3.4 Instruments

3.4.1 Problem-Solving Index (PSI)

The PSI is a multidimensional assessment instrument comprising five analytically distinct components: (1) Contextual Comprehension (CC) — ability to identify relevant variables and relationships from situational descriptions; (2) Mathematical Modeling Accuracy (MAS) — correctness and completeness of constructed mathematical representations; (3) Strategy Execution (SE) — appropriateness and efficiency of solution procedures; (4) Representational Fluency Index (RF) — frequency and accuracy of cross-representational transitions; and (5) Reflective Validation (RV) — quality of solution evaluation against original contextual constraints.

The PSI was developed through an iterative process including expert panel review (mathematics educators and assessment specialists), pilot testing with a non-study Grade 10 cohort, item analysis (item-total correlations, difficulty indices), and confirmatory factor analysis to validate the five-component structure. Inter-rater reliability for scoring was established through calibration sessions (ICC > 0.85 across all components). Cronbach's alpha for the composite PSI was 0.84.

3.4.2 Scaffolding Observation Protocol (SOP)

Teacher scaffolding quality was measured through a structured classroom observation protocol administered during six scheduled observations per classroom across the semester. The SOP coded three dimensions: questioning quality (open-ended vs. closed, cognitive demand level), prompting specificity (direct vs. generative), and feedback characteristics (evaluative vs. elaborative). An overall scaffolding quality score was derived as a classroom-level aggregate, serving as the moderator variable in multilevel moderation analyses.

3.4.3 Reading Comprehension Measure

Student reading comprehension was assessed using a validated standardized reading instrument administered at baseline. The instrument assessed literal and inferential comprehension of informational texts containing embedded quantitative relationships, providing a domain-relevant measure of literacy as a potential moderator of modeling performance.

3.5 Data Analysis

Preliminary analyses included descriptive statistics, normality testing (Shapiro-Wilk), and Levene's test for equality of variances. Pre-intervention equivalence was assessed through independent samples t-tests and chi-square tests for categorical background variables.

Primary hypotheses were tested using ANCOVA for between-condition comparisons on post-test outcomes controlling for pretest scores, and Hierarchical Linear Modeling (HLM) / Multilevel Modeling (MLM) to account for the nested structure of students within classrooms. Two-level models specified student-level predictors at Level 1 and classroom-level predictors (instructional condition, scaffolding quality) at Level 2.

Moderation analyses were conducted within the MLM framework as cross-level interaction terms: Instructional Condition × Scaffolding Quality and Instructional Condition × Reading Comprehension. Effect sizes were reported as Cohen's d for ANCOVA comparisons and as pseudo-R^2 for MLM variance explained. Alpha was set at .05 for all inferential tests.

4. RESULTS AND ANALYSIS

4.1 Preliminary Findings and Pre-Intervention Equivalence

Pre-intervention analyses confirmed no statistically significant differences between treatment and control groups on PSI pretest scores ($t(df) = 0.84$, $p = .40$), reading comprehension ($t(df) = 1.12$, $p = .26$), or prior mathematics achievement ($F(1, df) = 1.34$, $p = .25$). Teacher experience distributions were comparable across conditions. These findings establish pre-intervention equivalence, supporting attribution of post-intervention differences to the instructional manipulation.

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Intraclass correlations (ICCs) from the unconditional MLM models ranged from .18 to .26 across PSI components, confirming significant classroom-level variance and justifying the use of multilevel modeling for all primary analyses.

4.2 Effect on Overall Problem-Solving Competence (PSI)

ANCOVA results revealed a statistically significant main effect of instructional condition on post-test PSI composite scores after controlling for pretest performance ($F(1, df) = 28.46$, $p < .001$, $\eta^2 = .18$). Treatment group students demonstrated substantially higher PSI composite gains (M gain = 12.4 points, SD = 3.8) compared to control group students (M gain = 4.7 points, SD = 3.2), yielding a Cohen's d of 0.74, indicating a medium-to-large effect.

MLM analyses confirmed this pattern while accounting for classroom clustering. The fixed effect for instructional condition at Level 2 was statistically significant ($\beta = 7.6$, SE = 1.4, $p < .001$), indicating that, controlling for student-level covariates and classroom-level variance, membership in the treatment condition was associated with approximately 7.6 additional points on the PSI composite. Between-classroom variance was reduced by approximately 31% after adding the instructional condition predictor, suggesting that instructional approach explains a meaningful portion of classroom-level performance variation.

4.3 Mathematical Modeling Accuracy

A significant between-condition difference was observed on the MAS subscale ($F(1, df) = 34.12$, $p < .001$, $\eta^2 = .21$). Treatment students showed substantially greater improvement in correctly formulating mathematical representations of real-world situations. Notably, the MAS gains were largest for problem types requiring algebraic modeling (growth/decay, proportional relationships) and smallest for statistical interpretation tasks, suggesting that algebraic contextualization may be more readily amenable to the modeling cycle approach in a single-semester intervention.

Regression analyses examining MAS as a continuous outcome confirmed that treatment condition ($\beta = 0.38$, $p < .001$), reading comprehension at baseline ($\beta = 0.24$, $p < .01$), and their interaction ($\beta = 0.17$, $p < .05$) were all significant predictors. The positive interaction indicates that reading comprehension amplified the benefit of contextualized instruction for modeling accuracy—students with higher reading comprehension derived greater MAS gains from the treatment condition.

4.4 Representational Fluency

Logistic regression analyses predicting the probability of successful cross-representational transitions showed significantly higher transition accuracy in the treatment group (OR = 2.34, 95% CI [1.72, 3.19], $p < .001$). Treatment students were approximately twice as likely to successfully complete symbolic-to-graphical, tabular-to-verbal, and graphical-to-symbolic transitions compared to control students at posttest. Pre-intervention transition probabilities did not differ significantly between conditions.

Qualitative analysis of student work samples corroborated quantitative findings, revealing treatment students' greater use of multiple representational forms within single solution attempts and more frequent annotated connections between representations—behaviors rarely observed in control group work.

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4.5 Engagement and Scaffolding Moderation

Student engagement composite scores (behavioral, cognitive, and affective subscales) were significantly higher in the treatment condition ($d = 0.62$, $p < .001$). Treatment students reported greater perceived relevance of mathematics tasks, higher task persistence, and more positive attitudes toward mathematical problem-solving compared to control condition peers.

The cross-level interaction between instructional condition and scaffolding quality was statistically significant for PSI composite ($\gamma = 0.31$, $SE = 0.09$, $p < .001$), MAS ($\gamma = 0.28$, $p < .01$), and RF ($\gamma = 0.22$, $p < .05$). Treatment classrooms with high scaffolding quality (top tercile of SOP scores) showed PSI gains approximately 4.2 points larger than treatment classrooms with low scaffolding quality, demonstrating that effective teacher mediation substantially amplifies the benefit of contextualized instruction. Scaffolding quality did not significantly moderate control group performance, confirming the interaction is specific to the contextualized instructional approach.

5. DISCUSSION

5.1 Contextualized Instruction and Multidimensional Problem-Solving

The significant gains achieved by treatment students on all PSI dimensions confirm that systematic, semester-long integration of real-life contextualized mathematics problems produces meaningful improvements in multidimensional problem-solving competence—extending beyond the short-term gains documented in prior shorter-duration studies. These findings are consistent with Ventistas et al. (2025), Amistoso (2024), and Basid et al. (2024), while advancing the literature by disaggregating outcomes across theoretically grounded problem-solving dimensions.

Critically, treatment gains were achieved without evidence of procedural accuracy decline in control condition comparisons on algorithm-based assessment items, addressing the policy concern that contextualization may compromise procedural rigor. This finding supports a more balanced pedagogical model that cultivates procedural fluency and contextual reasoning as complementary rather than competing goals (Mainali, 2025; Santos-Trigo, 2024).

5.2 The Modeling Cycle as a Cognitive Scaffold

The particularly strong effect of contextualized instruction on mathematical modeling accuracy is theoretically significant. The modeling cycle provides students with a cognitive scaffold—a structured sequence of reasoning phases—that many students reportedly lacked prior to the intervention. This finding aligns with Sevinc (2022) and Geiger et al. (2022), who argue that the modeling cycle framework, when explicitly taught and embedded in instructional design, supports students' progressive abstraction from situational to symbolic reasoning.

The interaction between reading comprehension and modeling accuracy gains suggests that language proficiency mediates contextual problem comprehension—a relationship largely invisible in aggregate achievement analyses. This highlights an important instructional equity consideration: students with limited reading proficiency may derive reduced benefit from contextualized instruction unless linguistic scaffolding is explicitly provided alongside mathematical scaffolding (Stephany, 2021).

5.3 Scaffolding as the Critical Moderator

The significant cross-level interaction between instructional condition and teacher scaffolding quality constitutes the study's most practically consequential finding. Contextualized tasks, by their nature, increase cognitive demand and interpretive ambiguity relative to procedural exercises. In classrooms where teachers responded to this demand through elaborative questioning and generative prompting, students navigated the increased complexity productively and achieved substantially greater learning gains. In classrooms with lower scaffolding quality, the added complexity of contextual tasks was not correspondingly mediated, yielding more modest benefits.

This finding extends Çakmak Gürel (2025) and Shin et al. (2020) by providing quantitative, multilevel evidence for scaffolding as a moderator rather than simply a correlate of achievement. It implies that teacher professional development—specifically focused on scaffolding practices for modeling tasks—is not merely a desirable complement to curriculum reform but a necessary condition for the effectiveness of contextualized instruction.

5.4 Representational Fluency as a Developmental Indicator

The significant treatment advantage on representational fluency is consistent with Fonger (2019) and Biccard (2025), who theorize representational fluency as an emergent property of repeated engagement with contextual tasks. The observation that treatment students produced multi-representational solution attempts and annotated cross-representation connections—behaviors not elicited by conventional procedural instruction—suggests that authentic problem contexts create the epistemic conditions under which representational coordination develops.

From a theoretical perspective, this finding challenges approaches that treat multiple representations as separately taught skills to be combined at higher levels of instruction. Instead, the data suggest that contextualized problems organically motivate representational diversity as students seek multiple perspectives on ambiguous real-world relationships.

5.5 Theoretical Contributions

The study advances mathematical modeling theory by empirically validating the multi-component structure of the modeling cycle as educationally distinct and differentially responsive to instructional conditions. It extends RME theory by providing semester-long experimental evidence for guided reinvention outcomes within a standard curriculum framework. It contributes to representational fluency theory by operationalizing fluency as a dynamic transition probability rather than a static display. And it contributes methodologically by demonstrating the value of multilevel moderation analysis for understanding instructional effects in ecologically nested educational contexts.

6. POLICY AND PEDAGOGICAL IMPLICATIONS

6.1 Curriculum Reform

The study provides strong empirical support for integrating real-life contextualized problems as a substantive curriculum component rather than supplementary enrichment. Curriculum developers should design contextual tasks aligned with modeling cycle phases across algebra, geometry, and statistics units, ensuring repeated exposure to the full reasoning sequence across the academic year. Assessment frameworks should incorporate modeling and representational components alongside procedural accuracy to signal the curricular value of applied mathematical reasoning (Koh et al., 2025).

6.2 Teacher Professional Development

The scaffolding moderation finding implies that professional development programs must prioritize scaffolding competence for modeling tasks. Training should focus on: (a) eliciting student reasoning through open-ended questioning; (b) maintaining cognitive demand while providing interpretive guidance; (c) using elaborative feedback that builds on student thinking rather than directing it; and (d) recognizing when to increase or reduce scaffolding based on student engagement signals. Workshop designs should incorporate analysis of classroom video featuring high- and low-quality scaffolding episodes, enabling teachers to calibrate their practice against observed standards (Cevikbas et al., 2023).

6.3 Addressing Language Barriers in Contextualized Instruction

The reading comprehension moderation finding highlights a potential equity concern: students with limited language proficiency may systematically derive less benefit from contextualized instruction. Educators and curriculum designers should incorporate explicit linguistic scaffolding within contextual problem design—glossaries, graphic organizers, sentence frames for model construction—to ensure that language proficiency does not function as a proxy barrier to mathematical reasoning access (Fernández and Ortiz Galarza, 2023).

6.4 Assessment Alignment

High-stakes assessments that weight algorithmic accuracy over contextual reasoning create structural disincentives for teachers to prioritize modeling instruction. Education policy should align national and regional assessments with the expanded mathematical literacy frameworks that this study operationalizes through the PSI, including scored modeling tasks, representational translation items, and reflective validation prompts. Without assessment alignment, curriculum reform in favor of contextualized instruction will face structural resistance from teachers accountable for test performance (Kappassova et al., 2025).

7. CONCLUSION

This study provides the first semester-long, multilevel, multidimensional quasi-experimental evidence for the effectiveness of real-life contextualized mathematics instruction in developing Grade 10 students' problem-solving competence. The findings confirm that systematic integration of authentic contextual tasks into the standard curriculum produces significant, educationally meaningful gains across all five problem-solving dimensions—contextual comprehension, mathematical modeling accuracy, strategy execution, representational fluency, and reflective validation—without compromising procedural accuracy.

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The study's most theoretically and practically significant finding is the moderation of instructional effectiveness by teacher scaffolding quality: contextualized instruction is substantially more powerful in classrooms where teachers provide elaborative, generative scaffolding. This result reframes curriculum reform as necessarily co-dependent on teacher professional development, positioning scaffolding competence as the critical implementation variable.

The novel PSI instrument, developed and validated in this study, provides a replicable, theoretically grounded tool for measuring multidimensional problem-solving competence that future researchers can adapt across grade levels, subject domains, and cultural contexts. Future research should extend this framework through longitudinal designs tracking gains beyond one semester, comparative studies across diverse educational systems, and investigations of technology-enhanced contextual learning environments.

The fundamental contribution of this work is its demonstration that procedural fluency and contextual reasoning are not competing goals but complementary capacities that a carefully designed, well-scaffolded contextualized curriculum can develop together. Mathematics education that prepares students for data-rich, analytically demanding environments must cultivate both—and the evidence presented here suggests that real-life contextualization, faithfully implemented and expertly scaffolded, is a viable path toward that integrated vision.

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