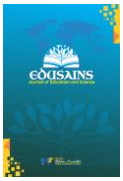
Published online on the page : https://journal.makwafoundation.org/index.php/edusains

Journal of Education and Science
(E D U S A I N S)

| ISSN (Online) 3030-8267 |



Effect of a Brain-Based Learning Approach on Grade VII Students' Mathematical Conceptual Understanding

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Article Information

Article History
Received: June 27, 2026
Revised: July 30, 2026
Accepted: September 4, 2026
Published: October 15, 2026

Keywords

Brain-based learning, Conceptual understanding, Mathematics education, Quasi-experiment, Junior secondary school

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A B S T R A C T

Conceptual understanding is a core goal of school mathematics, yet many Indonesian lower-secondary students can reproduce worked examples without being able to restate, represent, or apply the underlying concepts. Classroom evidence on brain-based learning (BBL) that documents its implementation and measurement in Islamic junior secondary schools remains limited. This study aimed to examine the effect of a BBL approach on the mathematical conceptual understanding of Grade VII students. A quasi-experimental posttest-only control group design was conducted at MTsN 12 Agam, West Sumatra, Indonesia, in the 2017/2018 academic year. After the four Grade VII classes were shown to be equivalent in mid-semester mathematics scores, two classes were assigned by lottery to the experimental group (BBL; n = 28) and the control group (expository instruction; n = 30). Instruction on the perimeter and area of triangles and quadrilaterals lasted three meetings, after which a four-item essay test covering four indicators of conceptual understanding was administered; the expert-validated test was reliable in a try-out (α = .78). The BBL class obtained a higher mean score (M = 78.64, SD = 14.57) than the control class (M = 65.50, SD = 17.73), $t(56) = 3.07$, p = .003, Hedges' g = 0.80, and a Mann–Whitney test confirmed the difference. The largest gap was found on the indicator of applying concepts to problem solving. The findings suggest that a structured BBL sequence can strengthen students' conceptual understanding in madrasah mathematics classrooms, although the single-class-per-condition design calls for replication with more classes.

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1. Introduction

Understanding a mathematical concept involves more than remembering a rule. Students who understand a concept can explain why a procedure works, connect different representations of the same idea, and use the idea in situations that differ from the examples they have practised. In the widely used model of mathematical proficiency, conceptual understanding is a strand that is distinct from, yet interwoven with, procedural fluency, strategic competence, and adaptive reasoning (National Research Council, 2001). Recent frameworks describe mathematical understanding as something that develops over time and must be made observable through students' explanations and justifications (Cai et al., 2026);(Keazer & Phaiah, 2023). Research on how people learn likewise highlights the interplay between learners' prior knowledge, the tasks they work on, and the learning environment (National Academies of Sciences, Engineering, and Medicine, 2018). International assessment results continue to show that many students struggle to reason with and apply mathematics (Organisation for Economic Co-operation and Development, 2023).

Weak conceptual understanding is also a recurring concern in Indonesian classrooms. Studies have reported low levels of conceptual understanding during the transition to post-

pandemic schooling (Fauziah et al., 2021) and have tested various instructional responses, including problem-based learning supported by GeoGebra (Putri & Susanto, 2023), cooperative learning of the Student Teams Achievement Division type (Aulani et al., 2025), scaffolding (Julanda et al., 2023), and the auditory–intellectually–repetition model (Mustika et al., 2021). Cooperative arrangements have also been associated with greater student activity and achievement in mathematics (Akbar et al., 2023). A recent systematic review of secondary mathematics confirms the variety of interventions being tried but notes that studies seldom specify how an intervention changes students' representations and reasoning (Atiqoh et al., 2026).

Brain-based learning (BBL) is an instructional approach that organizes lessons around active engagement, a supportive learning climate, links between new content and prior experience, collaborative processing, and repeated opportunities for practice and consolidation. Studies conducted with Indonesian junior high school students have reported that BBL was associated with better conceptual understanding than conventional instruction (Astuti & Umbara, 2022);(Sahid et al., 2020). Positive results have also been reported for primary students taught with BBL combined with open-ended problems (Suharja et al., 2024), for comparisons between BBL and problem-based learning (Maryam & Wahyudin, 2025), and for BBL assisted by GeoGebra (Nasution et al., 2025). Studies outside Indonesia have linked BBL to the acquisition of mathematical concepts and logical reasoning (Al-Habbar, 2024) and to achievement and retention in solving word problems (Udofia & Ibok, 2025). These studies, however, differ in learners' ages, in how BBL is operationalized, in the comparison condition, and in the outcome measure, so their results cannot simply be pooled.

A defensible account of BBL should rest on testable cognitive and instructional principles rather than on claims that particular activities stimulate specific parts of the brain. Work on element interactivity and working-memory load explains why manageable steps and scaffolded explanations can support learning (Chen et al., 2023);(Ngu & Phan, 2024). Coordinating verbal and visual information can aid sense making (Mayer, 2024), digital learning environments may add extraneous load (Skulmowski & Xu, 2022), and embodied activity offers principles that are relevant to mathematics learning (Way & Ginns, 2024). At the same time, critical reviews warn that "brain-friendly" teaching is vulnerable to neuromyths, such as learning styles or hemispheric dominance, and call for careful scrutiny of neuroscience-based recommendations (Grospietsch & Lins, 2021);(Hughes et al., 2022); (Rousseau, 2024);(Sullivan et al., 2021). From this perspective, the potential value of BBL lies in its instructional structure, which includes orientation, collaborative problem solving, elaboration, practice, verification, and consolidation, rather than in any direct neurological effect.

The broader literature on mathematics instruction points in a similar direction. Effective teaching for conceptual understanding tends to combine conceptual tasks with interaction, feedback, student explanation, and reflection (Castillo et al., 2025). Problem-based approaches can foster higher-order thinking, but they also pose practical implementation challenges (Aba-Oli et al., 2025);(Ssalia et al., 2025). Evidence from the science of learning shows that distributed practice and retrieval opportunities support retention (Dunlosky et al., 2013), including in mathematics (Lyle et al., 2022);(Murray et al., 2025);(Muzsnay et al., 2024). Because the BBL sequence includes repeated practice and verification phases, these principles offer a plausible explanation for why BBL may support understanding.

The need for such evidence was evident at MTsN 12 Agam, a state Islamic junior secondary school (madrasah tsanawiyah) in West Sumatra. Classroom observations on 25 and 26 October 2017 showed that Grade VII mathematics lessons were teacher-centred: the teacher explained the material, worked through examples, and assigned exercises and homework while most students remained passive. The mathematics teacher reported limited student interest and participation, little interaction among students, and responses coming mainly from high-achieving students, while interviews with students indicated that many memorized procedures and struggled when a problem differed from the examples. In the first-semester mid-term examination, only 17.86% to 25.00% of the students in each Grade VII class reached the minimum mastery criterion of 70. On the two conceptual-understanding items of that examination, only 25 of 117 students scored 70 or higher, with errors in applying fractions to an area problem and in representing sets with a Venn diagram.

Prior BBL studies have rarely been conducted in madrasah settings, and few have reported in detail the lesson phases, the equivalence of the groups, and the quality of the instrument used to assess conceptual understanding. This study addresses that gap by reporting a classroom comparison in which the BBL phases, the comparison condition, the procedure for establishing group equivalence, and the validity and reliability of the test are documented, and by analyzing the results across four indicators of conceptual understanding. The research question was: Is there a significant difference in mathematical conceptual understanding between Grade VII students taught with a BBL approach and those taught with conventional expository instruction? It was hypothesized that students in the BBL class would achieve higher conceptual understanding. The study is expected to provide context-specific evidence for mathematics teachers in madrasahs and to inform the design of future, larger evaluations of BBL.

2. Methods

2.1. *Research Design*

This study used a quantitative quasi-experimental approach with a posttest-only control group design, described in the original study as a static group comparison with randomized control-group-only design. Two intact classes were involved: an experimental class taught with the BBL approach and a control class taught with conventional instruction using an expository strategy. Both classes took the same conceptual understanding test after the instructional period. Because intact classes rather than individual students were assigned to conditions, equivalence between classes was established before assignment on the basis of mid-semester examination scores (Section 2.3).

2.2. *Research Setting and Participants*

The study was conducted at MTsN 12 Agam, a state Islamic junior secondary school in Agam Regency, West Sumatra Province, Indonesia, during the second semester of the 2017/2018 academic year. The population comprised all 117 Grade VII students in four classes: VII.1 (n = 31), VII.2 (n = 30), VII.3 (n = 28), and VII.4 (n = 28). The sample consisted of two classes: VII.3 as the experimental class (n = 28) and VII.2 as the control class (n = 30), for a total of 58 students. Class VII.4 (n = 28) served as the try-out group for the test instrument.

2.3. *Sampling Procedures*

The first-semester mid-term examination scores of the four classes were analyzed to ensure that the classes were comparable before assignment. All four classes were normally distributed according to the Lilliefors test (L_0 = 0.0939, 0.0858, 0.1300, and 0.1094, each below its critical value of 0.161–0.175) and the MINITAB normality test (p = .295–.763). Their variances were homogeneous according to Bartlett's test ($\chi^2(3) = 1.67 < 7.81$; MINITAB p = .644), and a one-way analysis of variance showed no difference in class means (F = 0.04 < Fcrit = 2.68; p = .990). Because the classes were equivalent, two classes were selected by lottery: the class names were written on rolled slips of paper and drawn at random, with the first class drawn (VII.3) assigned to the experimental condition and the second (VII.2) to the control condition. Formal justification of sample size, as recommended for future studies (Lakens, 2022), was not undertaken because the study used existing intact classes.

2.4. *Intervention and Comparison Conditions*

The topic taught in both classes was the perimeter and area of triangles and quadrilaterals. Each class received three lessons of 80 minutes (10 minutes of introduction, 60 minutes of core activities, and 10 minutes of closure), followed by the posttest; all lessons in both classes were taught by the second author. The experimental class was taught on 26 April, 3 May, and 8 May 2018 and the control class on 28 April, 5 May, and 8 May 2018. Lesson plans for both classes and student worksheets for the experimental class were reviewed by experts before use (Section 2.6). The BBL lessons followed seven phases: (1) pre-exposure, in which a mind map of the topic was displayed and the learning objectives were stated; (2) preparation, consisting of a brief brain-gym activity and an introduction that linked the topic to everyday situations; (3) initiation and acquisition, in which students worked on student worksheets in small heterogeneous groups; (4) elaboration, involving teacher-guided group discussion, group presentations, and question-and-answer sessions; (5) incubation and memory encoding, in which students watched a short inspirational video and then completed practice exercises; (6) verification and confidence checking, in which students solved more challenging problems and checked their work with the teacher; and (7) celebration and integration, in which students formulated conclusions, received homework, and took part in a brief celebration such as applause or small rewards.

The control class received conventional expository instruction. After greeting the class, taking attendance, praying, reviewing prior material, and stating the objectives, the teacher explained the material, presented worked examples, posed questions to the class, and assigned practice exercises. Each lesson ended with a short quiz, homework, and a reminder to read the next material.

2.5. *Research Instrument*

Conceptual understanding was measured with a written essay test consisting of four items, one for each indicator of conceptual understanding: restating a concept (Item 1, the area of a triangular roof cross-section), using and selecting appropriate procedures or operations (Item 2, the perimeter of a parallelogram given its area and heights), presenting a concept in a mathematical representation (Item 3, a diagonal of a rhombus given its area and the other diagonal), and applying a concept or algorithm to problem solving (Item 4, the area of a composite plane figure). Each item was scored from 0 to 4 with an analytic rubric for its

indicator, in which 0 indicates no answer and 4 indicates a complete and correct response. The final score was computed as the total item score divided by the maximum score of 16 and multiplied by 100. Scores were interpreted as very good (85.00–100), good (70.00–84.99), fair (55.00–69.99), low (40.00–54.99), or very low (0.00–39.99), and the school's minimum mastery criterion was 70. Students were given 80 minutes to complete the test. Distinguishing conceptual explanation from procedural execution in this way is consistent with current approaches to assessing mathematical understanding (Keazer & Phaiah, 2023);(Schulz, 2024).

2.6. *Validity and Reliability*

Content validity of the lesson plans, the student worksheets, and the test was established by two mathematics lecturers and one mathematics teacher, who judged the test usable with minor revisions. The test was then tried out on 4 May 2018 with 28 students in class VII.4, which was not part of the sample. Item–total Pearson correlations ranged from 0.757 to 0.800, all exceeding the critical value of 0.374 ($\alpha = .05$, $df = 26$) and falling in the high category. Internal consistency, estimated with Cronbach's alpha, was 0.782, indicating high reliability. Item difficulty indices ranged from 0.545 to 0.634 (moderate), and discrimination indices ranged from 0.34 to 0.48 (good to very good). Consequently, all four items were retained for the posttest.

2.7. *Data Collection and Analysis*

The posttest was administered to the control class on Saturday, 12 May 2018, and to the experimental class on Tuesday, 15 May 2018. Descriptive statistics, mastery rates, score categories, and mean item scores were computed for each class. Normality was examined with the Lilliefors test and the Shapiro–Wilk test, and homogeneity of variance was examined with the F test and Levene's test. The hypothesis was tested with an independent-samples t test with pooled variance at $\alpha = .05$, and a 95% confidence interval for the mean difference and Hedges' g with its 95% confidence interval were reported. Because one distribution showed a slight departure from normality, a Mann–Whitney U test was also conducted as a robustness check. All analyses were based on the individual scores listed in the appendix of the original study. For the control class, these scores sum to 1,965 (M = 65.50), slightly different from the total of 1,952 (M = 65.07) printed in the original summary; the conclusions are the same under either version. Calculations were performed manually and verified with MINITAB and Python (SciPy).

2.8. *Ethical Considerations*

The study was conducted with a research permission letter from the authors' institution and the approval of the school, and the research schedule was agreed with the Grade VII mathematics teacher. The lessons in both classes covered the regular curriculum topic, and the test was administered as part of normal classroom activities. Students' names were not used in the analysis, and all results are reported anonymously and in aggregate form.

3. Results

3.1. *Descriptive Statistics*

Table 1 summarizes the posttest scores of the two classes.

Table 1. Posttest scores for mathematical conceptual understanding

Statistic	Experimental (BBL)	Control (expository)

Number of students	28	30
Mean	78.64	65.50
Standard deviation	14.57	17.73
Median	78.50	63.00
Minimum	44	38
Maximum	100	94
Students reaching mastery (≥ 70)	21 (75.0%)	12 (40.0%)

The experimental class had a mean score 13.14 points higher than the control class, and 75.0% of its students reached the mastery criterion, compared with 40.0% in the control class. The control class also showed greater dispersion. Table 2 presents the distribution of students across the score categories.

Table 2. Distribution of students by conceptual understanding category

Category	Score range	Experimental *f* (%)	Control *f* (%)
Very good	85.00–100	8 (28.6)	5 (16.7)
Good	70.00–84.99	13 (46.4)	7 (23.3)
Fair	55.00–69.99	5 (17.9)	10 (33.3)
Low	40.00–54.99	2 (7.1)	4 (13.3)
Very low	0.00–39.99	0 (0.0)	4 (13.3)

Three quarters of the students in the experimental class were in the good or very good categories, and none were in the very low category. In the control class, 40.0% were in the good or very good categories and 26.7% were in the low or very low categories.

3.2. *Results by Indicator*

Table 3 presents the mean item scores (maximum = 4) for each indicator of conceptual understanding.

Table 3. Mean item scores by indicator of conceptual understanding (maximum score = 4)

Indicator (item)	Experimental	Control	Difference
Restating a concept (Item 1)	3.21	3.00	0.21
Using and selecting procedures (Item 2)	3.18	3.00	0.18
Representing a concept (Item 3)	3.14	2.89	0.25
Applying a concept (Item 4)	3.00	2.21	0.79
Overall mean item score	3.13	2.78	0.35

The experimental class scored higher on all four indicators. The gaps were small for restating a concept, selecting procedures, and representing a concept (0.18–0.25 points) but considerably larger for applying a concept to problem solving (0.79 points). On this item, 13 of the 28 students in the experimental class (46.4%) obtained the maximum score and only one scored below 2, whereas in the control class 9 of the 30 students (30.0%) scored 0 or 1. The sample answers in the original study illustrate this: a typical answer in the experimental class applied the area concepts to the composite figure completely and correctly (score 4), whereas a typical answer in the control class reached a total area without applying the concepts accurately (score 2).

3.3. *Prerequisite Tests*

The Lilliefors test indicated that both distributions were consistent with normality (experimental: $L_0 = 0.123 < 0.167$; control: $L_0 = 0.089 < 0.161$). The Shapiro–Wilk test indicated normality for the control class ($W = 0.942$, $p = .106$) but a slight departure for the experimental

class (W = 0.925, p = .047). Variances were homogeneous (F = 1.48 < Fcrit(29, 27) = 1.89; Levene's $F(1, 56)$ = 1.63, p = .207). The t test was therefore used as the main analysis, and the Mann–Whitney U test was added as a robustness check.

3.4. *Hypothesis Testing*

Table 4 presents the results of the hypothesis tests.

Table 4. Comparison of posttest scores between the experimental and control classes

Statistic	Value	Interpretation
Mean difference	13.14	—
95% CI for mean difference	[4.57, 21.71]	Excludes zero
Pooled-variance t test	$t(56)$ = 3.07, p = .003	Significant
One-tailed p (H_1: $\mu_1 > \mu_2$)	.002	Significant
Welch's t test	$t(55.1)$ = 3.09, p = .003	Significant
Mann–Whitney U test	U = 604.5, p = .004	Significant
Hedges' g [95% CI]	0.80 [0.26, 1.33]	Large

Note. CI = confidence interval. p values are two-tailed unless stated otherwise.

The mean posttest score of the experimental class was significantly higher than that of the control class, $t(56)$ = 3.07, p = .003, with a mean difference of 13.14 points (95% CI [4.57, 21.71]). The one-tailed test of the directional hypothesis was also significant (p = .002), as were Welch's t test and the Mann–Whitney U test, so the conclusion does not depend on the normality or equal-variance assumptions. The effect size was large, Hedges' g = 0.80, 95% CI [0.26, 1.33]. Analysis of the summary values printed in the original study (control M = 65.07, SD = 18.57) produced nearly identical results, $t(56)$ = 3.08, p = .003, g = 0.80. The null hypothesis was therefore rejected: students taught with the BBL approach showed significantly higher mathematical conceptual understanding than students taught with expository instruction.

4. Discussion

The main finding of this study is that Grade VII students taught with the BBL approach achieved significantly higher conceptual understanding than students who received expository instruction, with a large standardized difference and a much higher proportion of students reaching the mastery criterion. Because the classes had been shown to be equivalent in mid-semester mathematics scores before assignment, and because the same teacher taught both classes the same topic over the same number of lessons, the difference is unlikely to be explained by initial class differences or teacher differences alone. The result therefore supports the hypothesis that the BBL sequence improved students' conceptual understanding, while acknowledging that only one class was assigned to each condition.

The finding is consistent with Indonesian studies reporting that BBL improves junior high school students' conceptual understanding (Astuti & Umbara, 2022);(Sahid et al., 2020) and with studies that combined BBL with open-ended problems or GeoGebra (Nasution et al., 2025);(Suharja et al., 2024). It also aligns with comparisons of BBL and problem-based learning (Maryam & Wahyudin, 2025) and with international studies linking BBL to concept acquisition and to achievement and retention in word problems (Al-Habbar, 2024);(Udofia & Ibok, 2025). The present study extends this evidence to a madrasah tsanawiyah context and reports the lesson phases, the procedure for establishing group equivalence, and the test properties in detail, which allows the result to be interpreted and replicated more readily.

The indicator-level results help to explain where the approach made the greatest difference. The gaps were modest for restating a concept, selecting procedures, and representing a concept, which students in both classes could largely do after instruction. The clearly larger gap on applying a concept to an unfamiliar composite figure is consistent with the problems identified at the outset, namely that students could solve problems resembling the teacher's examples but struggled with problems in a different form. Distinguishing between carrying out a procedure and applying a concept with understanding is central in mathematics assessment (Keazer & Phaiah, 2023);(Schulz, 2024), and students' metacognitive knowledge plays a role in how they approach such problems (Toikka et al., 2024).

Several elements of the BBL sequence offer plausible explanations for this pattern, interpreted through established learning principles rather than neurological claims. Group work on worksheets during the acquisition phase required students to construct relationships between figures and formulas themselves, and the elaboration phase required them to explain and defend their solutions, which supports conceptual understanding (Castillo et al., 2025). The sequence moved from guided examples to more challenging problems with checking, which is consistent with managing element interactivity and cognitive load (Chen et al., 2023);(Ngu & Phan, 2024). The incubation and verification phases provided repeated practice and retrieval within and across lessons, which research has linked to better retention (Dunlosky et al., 2013);(Lyle et al., 2022);(Murray et al., 2025);(Muzsnay et al., 2024). Mind maps and figures provided coordinated verbal and visual information (Mayer, 2024);(Skulmowski & Xu, 2022), and the brief physical and celebratory activities may have supported engagement in ways that research on embodied learning considers relevant (Way & Ginns, 2024). Interpreting BBL in these terms also avoids the neuromyths that critical reviews have identified (Grospietsch & Lins, 2021);(Hughes et al., 2022);(Rousseau, 2024);(Sullivan et al., 2021).

The results also contribute to the broader discussion of active learning in Indonesian mathematics classrooms. Other approaches, such as scaffolding, Student Teams Achievement Division, problem-based learning with GeoGebra, the auditory–intellectually–repetition model, and Jigsaw, have likewise been reported to improve conceptual understanding or achievement (Akbar et al., 2023);(Aulani et al., 2025);(Julanda et al., 2023);(Mustika et al., 2021);(Putri & Susanto, 2023), and reviews of problem-based learning show that active tasks supported by teacher facilitation can foster reasoning but require careful implementation (Aba-Oli et al., 2025);(Ssalia et al., 2025). What these approaches share with BBL is a shift from passive reception to student activity, discussion, and practice. The present findings suggest that the structured phases of BBL offer teachers a concrete way to organize such a shift. The difficulties observed during implementation, including some students' initial reluctance to work in assigned groups and their unfamiliarity with the worksheets in the first meeting, diminished in later meetings, indicating that students need time to adapt to the approach.

Practically, the findings suggest that mathematics teachers in madrasahs can use BBL phases to structure lessons on geometry topics, with particular attention to worksheet-based group work, explanation of solutions, and progressively more challenging verification problems. Teachers should also plan the time allocation carefully, because the seven phases must fit within a single lesson. Developing teachers' ability to notice and interpret students' mathematical thinking during group work and presentations would further strengthen such lessons (Jacobs et al., 2024);(McCulloch et al., 2023);(Wei et al., 2023);(Weyers et al., 2024).

Several limitations should be acknowledged. First, only one intact class was assigned to each condition, so class-level factors cannot be fully separated from the effect of the approach, and the analysis treated students as independent observations. Second, although the classes were equivalent on mid-semester scores, no pretest of conceptual understanding on the topic taught was administered. Third, the intervention was short (three lessons) and was taught by one of the researchers, so no separate measure of implementation fidelity was obtained. Fourth, the test consisted of four items, one per indicator, which limits the precision of the indicator-level results. Fifth, the data were collected in 2017/2018 in a single madrasah, and the individual scores in the original appendix differed slightly from the printed summary for the control class. Future studies should involve more classes and schools, include pretests, use longer interventions with fidelity checks, and employ instruments with several items per indicator.

5. Conclusion

This study concludes that the BBL approach had a significant positive effect on the mathematical conceptual understanding of Grade VII students at MTsN 12 Agam. Students taught with BBL outperformed those taught with expository instruction, with a large effect size, a higher proportion of students reaching mastery, and the clearest advantage on applying concepts to problem solving. The study contributes classroom evidence from a madrasah setting in which the BBL phases, group equivalence, and instrument quality are documented, and it interprets the effect through established learning principles rather than neurological claims. These findings imply that structured BBL lessons can serve as a practical alternative to teacher-centred instruction for geometry topics in junior secondary mathematics. Because the study involved one class per condition, a short intervention, and no topic-specific pretest, the results should be generalized with caution, and future research should replicate the comparison with more classes, pretests, and longer interventions. Overall, organizing mathematics lessons around active, collaborative, and well-sequenced learning phases appears to help students move from imitating procedures to understanding and applying concepts.

Declarations

Author Contribution Statement

Putri Diana: conceptualization of the article, re-analysis of the data, writing—original draft of the manuscript, and correspondence with the journal. Siska Septia: investigation, including classroom observation, development and try-out of the lesson plans, worksheets, and test, implementation of the lessons in both classes, and data collection; data curation; and initial data analysis. Zebbil Billian Tomi: literature review and writing—review and editing. Mhd Furqan Akbar: verification of the statistical analysis, preparation of tables, and writing—review and editing. All authors read and approved the final manuscript.

Funding Statement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request. Individual student records are not publicly available in order to protect the privacy of minors.

Declaration of Interests Statement

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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