

Development of Augmented Reality media Based on Central Javanese Traditional Foods to Improve Fraction Numeracy Skills in Elementary School Students

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Abstract

Fraction numeracy is an essential competency for elementary school students; however, the abstract nature of fractions remains a challenge in mathematics learning. This study aimed to develop and evaluate the validity, practicality, and effectiveness of "Pecah Rasa," an Augmented Reality (AR) learning medium integrating traditional Central Javanese foods to support elementary school students' fraction numeracy skills. The study employed a *Research and Development* (R&D) approach using the ADDIE model, comprising *analysis, design, development, implementation, and evaluation*. The implementation involved 49 fourth-grade students from SDN Bener 01 Tenganan and SDN Gubug 01. Data were collected through observations, interviews, questionnaires, documentation, and pretest-posttest assessments and analyzed using descriptive and inferential statistics. The validation results yielded a mean score of 4.80 from the media expert, categorized as very good, and 3.00 from the material expert, categorized as fairly good and feasible for implementation after revision. The practicality score reached 81.91%, indicating that the medium was highly practical. Students' mean fraction numeracy score increased from 53.20 on the pretest to 87.12 on the posttest, with a statistically significant difference ($p < .001$) and an N-Gain of 0.72489, classified as high. These findings indicate that "Pecah Rasa" demonstrated adequate validity and practicality and has the potential to support improvements in fraction numeracy through AR visualizations that connect abstract mathematical concepts with concrete and culturally familiar objects. However, given the absence of a control group, the effectiveness findings should be interpreted cautiously and further verified through controlled experimental studies.

Keywords: *Augmented Reality, Fraction numeracy, Local culture, Pecah Rasa, Traditional foods.*

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I. INTRODUCTION

Education is a lifelong learning process that plays a strategic role in developing individuals' capacities to think, behave, and act effectively in response to various life challenges (Sudrajat & Hariati, 2021). In the 21st century, the orientation of education has expanded beyond knowledge transmission toward the development of more complex competencies, including critical thinking, creativity, communication, and collaboration required in modern society and an increasingly digital environment (Kamal, 2025). Consistent with the implementation of the Kurikulum Merdeka (Independent Curriculum), elementary education is expected to provide meaningful, contextual, and student-centered learning experiences through relevant instructional approaches and technologies. Accordingly, instruction should not merely enable students to acquire theoretical knowledge but should also provide opportunities to connect what they learn with problems and experiences encountered in everyday life.

One fundamental competency that needs to be developed through elementary mathematics education is numeracy. Numeracy encompasses the ability to understand, use, interpret, and communicate numerical concepts and mathematical operations to solve contextual problems effectively (Adim & Bahri, 2025). This competency provides an important foundation for logical reasoning, analytical thinking, problem solving, and decision making. In everyday contexts, numeracy is also required when students engage in activities such as calculating, measuring, comparing, estimating, and interpreting quantitative information. Strengthening numeracy at the elementary level is therefore essential for equipping students with the ability to use mathematical knowledge functionally across different situations.

However, developing numeracy remains challenging, particularly in learning fractions. Fractions are among the mathematical concepts that students often find difficult because of their abstract nature and the need to understand relationships between parts and wholes (Lahacila et al., 2024).

Difficulties may arise when students are required to understand different representations of fractions, compare fractional values, and perform addition and subtraction operations. These difficulties may become more pronounced when instruction emphasizes procedural memorization rather than the construction of conceptual understanding. Hidayatullah and Zainil (2025) explained that students' limited understanding of fractions is associated with conventional and teacher-centered instruction, limited use of concrete learning media, and insufficient connections between mathematical concepts and students' everyday experiences.

Similar problems were identified through preliminary observations and the researchers' teaching experiences in elementary school. Fraction instruction was predominantly characterized by lectures, simple drawings on the board, and exercises from textbooks. Fractions tended to be introduced symbolically with limited concrete and contextual visualization. Consequently, students experienced difficulties connecting fraction symbols with representations of real objects, particularly when understanding part-whole relationships. Abstract illustrations such as circles or squares divided into several sections were not always sufficient when these representations were disconnected from objects familiar to students. These conditions were accompanied by limited classroom engagement, low interest in mathematics, and difficulties in solving numeracy problems involving the addition and subtraction of fractions.

Theoretically, the need for concrete representations is consistent with the cognitive characteristics of elementary school students at the concrete operational stage. From Piaget's perspective of cognitive development, students at this stage construct understanding more readily when concepts are presented through concrete objects, visual representations, and direct experiences related to their everyday lives (Rahmaniar et al., 2022). Mathematics instruction therefore requires learning media capable of bridging abstract fraction concepts with more concrete, visual, and interactive representations. Media that are relevant to students' experiences may not only facilitate conceptual understanding but also enhance engagement and create more meaningful learning experiences.

Advances in digital technology provide opportunities to offer such representations through more interactive learning media. One technology with considerable potential for mathematics education is Augmented Reality (AR). AR enables two- or three-dimensional virtual objects to be integrated into real-world environments in real time through digital devices such as smartphones or tablets (Aditia, 2024). Through this technology, students can observe and interact with virtual representations more directly, allowing concepts previously presented only through symbols or static images to be visualized more concretely. In mathematics education, these characteristics enable AR to support students' understanding of abstract concepts through more tangible and interactive visual representations (Resti et al., 2024).

The potential of AR in mathematics education has been supported by several previous studies. Puspasari et al. (2024) demonstrated that AR-based learning media effectively supported students' understanding of fractions by presenting mathematical concepts through concrete and interactive visualizations. Anggiani et al. (2025) similarly reported improvements in students' understanding of fraction concepts through AR-based media compared with conventional instruction. Beyond cognitive outcomes, AR may also influence students' learning experiences. Asyaroh et al. (2021) found that AR-based media could enhance learning motivation and interest by making instruction more engaging, less monotonous, and more experiential. Collectively, these findings demonstrate the potential of AR to bridge the abstract nature of fractions with elementary students' need for concrete and interactive representations.

Nevertheless, innovation in instructional media should consider not only technological sophistication but also the contextual relevance of the representations provided. Previous research on AR in mathematics education has largely focused on the development and use of the technology as a visualization medium, while its integration with local cultural contexts remains relatively limited. Contexts that are familiar to students may facilitate connections between mathematical concepts and everyday experiences. Integrating local culture into mathematics learning may also provide additional educational value by introducing and preserving local knowledge and cultural heritage.

One cultural context that can be used to represent fraction concepts is traditional Central Javanese food, including getuk, klepon, serabi, apem, and lumpia. The shapes and ways in which these foods can be divided provide familiar representations of part-whole relationships, such as halves and quarters. Traditional foods can therefore function not merely as cultural elements but also as mathematical contexts for connecting concrete representations with fraction symbols. The use of local culture in instruction may contribute to more contextual learning experiences while simultaneously fostering students' appreciation of their cultural identity (Wahyuni, 2024).

Integrating traditional Central Javanese foods with AR technology offers an opportunity to combine the strengths of local contexts and digital visualization in fraction learning. Through three-dimensional representations and simulations of object partitioning, students can visually observe how an object is divided into several parts and how those parts can be used to represent the addition and subtraction of fractions. Interaction with these virtual objects may help bridge concrete, visual, and symbolic representations so that fractions are understood as more than mathematical procedures. At the same time, traditional food contexts can situate mathematical concepts within experiences familiar to students while introducing local cultural values through mathematics learning.

Previous research has demonstrated the potential of integrating local culture with AR technology. Febriyanto et al. (2025) and Ulya (2025) reported that incorporating local cultural elements into AR-based learning media can support mathematical conceptual understanding and create more meaningful learning experiences. However, research specifically developing AR media that uses traditional Central Javanese foods as contextual representations for teaching the addition and subtraction of fractions with like denominators at the elementary school level remains limited. This gap highlights the need for learning media that not only visualize fractions through AR technology but also connect these digital representations with cultural objects familiar to students.

Based on this gap, the novelty of the present study lies in the development of Augmented Reality learning media that integrates traditional Central Javanese foods as visual and mathematical contexts for learning the addition and subtraction of fractions with like denominators. This integration is designed to bridge concrete, visual, and symbolic representations, enabling students to construct an understanding of fractions through contexts closely connected to their everyday experiences. Accordingly, this study aims to develop and evaluate Augmented Reality learning media based on traditional Central Javanese foods to support the improvement of elementary school students' fraction numeracy skills.

II. METHOD

This study employed a Research and Development (R&D) approach to develop an Augmented Reality (AR)-based learning medium incorporating traditional Central Javanese foods for teaching the addition and subtraction of fractions with like denominators and to evaluate its validity, practicality, and effectiveness in supporting the improvement of elementary school students' fraction numeracy skills. The R&D approach was selected because the study focused not only on developing an instructional product but also on evaluating its feasibility for use in the learning process (Sugiyono, 2018). The development process followed the ADDIE model, comprising five stages: analysis, design, development, implementation, and evaluation. The ADDIE model was selected because it provides a systematic and structured procedure suitable for developing technology-enhanced learning media (Rayanto, 2020).

The analysis stage focused on identifying instructional needs, student characteristics, and challenges encountered in mathematics learning, particularly in relation to fractions. The findings from the needs analysis served as the basis for determining the characteristics and content of the learning medium. During the design stage, the structure and interface of the medium were designed, instructional content on the addition and subtraction of fractions with like denominators was organized, the application storyboard was developed, and the research instruments were prepared. Traditional Central Javanese foods were incorporated into the design as concrete representations to help students connect part-whole relationships with fraction symbols and operations.

The development stage involved constructing the AR-based learning medium using Unity and Vuforia. At this stage, traditional Central Javanese foods were developed as visual objects to

represent fraction concepts in a more concrete and interactive manner. The resulting product was subsequently validated by material and media experts to evaluate the appropriateness of its content, presentation, and technical characteristics. Feedback and recommendations from the experts were used as the basis for revising the product before its implementation in the learning process.

The implementation stage involved fourth-grade students from SDN Bener 01 Tenganan and SDN Gubug 01. Participants were selected using purposive sampling based on considerations relevant to the objectives of the study. The developed medium was implemented to obtain evidence regarding its practicality and changes in students' fraction numeracy skills following its use. The subsequent evaluation stage examined the implementation results and user feedback to identify the strengths and limitations of the medium and aspects requiring further refinement.

Data were collected through questionnaires, tests, observations, and documentation. Questionnaires were used to obtain data related to the validity and practicality of the developed medium, whereas tests were administered to assess students' fraction numeracy skills. Observation and documentation provided supporting information regarding the implementation and use of the medium during the learning process. Prior to data collection, the research instruments were evaluated in terms of validity, reliability, item difficulty, and discriminating power to ensure their quality. Quantitative and qualitative descriptive analyses were employed according to the characteristics of the data collected. Quantitative data were used to evaluate the validity, practicality, and effectiveness of the developed medium, while qualitative data derived from comments, suggestions, observations, and user feedback were used to support product evaluation and refinement. The AR-based learning medium incorporating traditional Central Javanese foods was considered feasible for instructional use when it satisfied the predetermined criteria for validity, practicality, and effectiveness.

III. RESULTS AND DISCUSSION

A. Results

This study produced an Augmented Reality (AR)-based learning medium called "Pecah Rasa," developed to support elementary school students in understanding the addition and subtraction of fractions with like denominators through concrete visual representations incorporating local cultural contexts. The medium was developed using Unity and Vuforia with a marker-based tracking system and can be operated through smartphones or tablets. The development of "Pecah Rasa" followed the five stages of the ADDIE model: analysis, design, development, implementation, and evaluation. The outcomes of each development stage provided the basis for producing a learning medium that was subsequently evaluated in terms of its validity, practicality, and effectiveness.

During the analysis stage, observations and interviews were conducted to identify the existing conditions of mathematics instruction, student characteristics, and difficulties encountered in learning the addition and subtraction of fractions with like denominators. The analysis indicated that some students continued to experience difficulties understanding fraction concepts because instruction tended to present the material abstractly and was predominantly based on teacher explanations. Students were more likely to memorize problem-solving procedures than to develop a concrete understanding of part-whole relationships. The use of interactive learning media was also limited, resulting in relatively few opportunities for students to explore fraction concepts through visual representations.

The analysis of student characteristics further indicated a need for learning media capable of bridging abstract fraction concepts with more concrete and observable representations. Based on these needs, AR was selected as the visualization technology and integrated with traditional Central Javanese foods familiar to students. These local cultural objects were used to represent part-whole relationships and fraction operations through interactive visualizations.

During the design stage, the structure and interface of "Pecah Rasa" were designed, instructional materials were organized, a storyboard was developed, AR markers were created, and research instruments were prepared, including validation sheets, response questionnaires, observation sheets, and pretest-posttest items. The instructional content focused on the addition and subtraction of fractions with like denominators, using traditional Central Javanese foods as

visual contexts. The application interface was designed to be simple and appropriate for elementary school students through the use of visual icons, engaging displays, and a menu structure that could be easily recognized and operated.

The development stage resulted in the “Pecah Rasa” application, which integrates fraction learning materials with AR visualizations of traditional Central Javanese foods. The medium contains several main features, including user guidance, student activities, instructional materials, and assessments. These features were organized to provide a systematic learning sequence, ranging from the introduction of learning materials and exploration of AR objects to practice activities and learning evaluation. Through the AR feature, students can scan markers using the device camera to display three-dimensional representations used to visualize fraction concepts.



Figure 1. Interface of the “Pecah Rasa” Learning Medium and Practice Exercises

Figure 1 presents the interface of “Pecah Rasa” and one of the practice exercise features available within the application. The main page provides access to several learning menus, including user guidance, student activities, instructional materials, and assessments. Practice exercises connect fraction operations with representations of traditional Central Javanese foods through a combination of textual and visual information. This design enables students to encounter fraction concepts not only as mathematical symbols but also through visual objects incorporated into the learning medium.

During the implementation stage, “Pecah Rasa” was used in teaching the addition and subtraction of fractions with like denominators to fourth-grade students at SDN Bener 01 Tenganan and SDN Gubug 01. Students operated the medium using smartphones or tablets and scanned markers depicting traditional Central Javanese foods to display three-dimensional objects on their devices. The learning activities included an introduction to the medium, exploration of AR features, use of visual objects to understand fraction operations, completion of practice exercises, and learning evaluation. During implementation, the teacher acted as a facilitator who provided guidance and assistance in using the medium. Observations indicated that students actively engaged in exploring the AR objects and participating in the learning activities provided through the application.

The evaluation stage was conducted to assess the validity, practicality, and effectiveness of “Pecah Rasa.” The evaluation was based on material and media expert validation, teacher and student responses, and pretest and posttest results. Before broader implementation, the developed product underwent expert validation to evaluate the appropriateness of the instructional content, media design and interface, application navigation, interactivity, and alignment with the learning objectives for fractions. Feedback obtained during the validation

process was also used as a basis for refining the product. The validation results for the “Pecah Rasa” learning medium are presented in Table 1.

Table 1. Validation Results of the “Pecah Rasa” Learning Medium

No.	Type of Validation	Score Range	Mean Score	Category	Decision
1	Material Expert	1–5	3.00	Fairly Good	Eligible for testing with revisions
2	Media Expert	1–5	4.80	Very Good	Eligible for testing
3	Teacher	1–4	3.45	Good	–
		1–4	3.87	Good	–
		1–4	3.93	Very Good	–
		1–4	3.87	Good	–
4	Students	1–4	3.04	Good	–
		1–4	3.50	Good	–

As shown in Table 1, the “Pecah Rasa” learning medium received positive evaluations from the validators and users. Media expert validation yielded a mean score of 4.80, categorized as very good, indicating that the medium met the media-related feasibility requirements and could proceed to the testing stage. Material expert validation yielded a mean score of 3.00, categorized as fairly good, and the product was considered eligible for testing after revision. The revisions primarily focused on refining the instructional content and simplifying the language to better accommodate the characteristics of elementary school students. Teacher evaluations ranged from 3.45 to 3.93, corresponding to good to very good categories, while student responses ranged from 3.04 to 3.50 and were categorized as good. Overall, these findings supported proceeding to the implementation stage after incorporating the revisions recommended by the validators.

Following product validation and revision, the effectiveness of “Pecah Rasa” was evaluated by examining changes in students’ fraction numeracy skills before and after instruction. Students completed a pretest before using the learning medium and a posttest after completing the instructional activities. The mean scores for both measurements are presented in Table 2.

Table 2. Pretest and Posttest Results

Assessment	Mean Score
Pretest	53.20
Posttest	87.12

As presented in Table 2, the mean fraction numeracy score increased from 53.20 on the pretest to 87.12 on the posttest, representing a mean increase of **33.92 points**. Descriptively, these results indicate an improvement in students’ fraction numeracy skills following instruction using the “Pecah Rasa” learning medium. However, the observed difference in mean scores alone does not establish statistical significance. Therefore, a normality test was conducted before examining the statistical significance of the pretest–posttest difference as a prerequisite for parametric analysis.

Table 3. Normality Test Results

Assessment	K–S Statistic	df	Sig.	S–W Statistic	df	Sig.
Pretest	0.102	49	0.200*	0.972	49	0.445
Posttest	0.095	49	0.200*	0.981	49	0.177

The normality test results presented in Table 3 indicate that both pretest and posttest scores satisfied the normality assumption. The Shapiro–Wilk test yielded significance values of 0.445 for the pretest and 0.177 for the posttest, both exceeding the 0.05 significance level. The Kolmogorov–Smirnov test similarly yielded significance values of 0.200 for both measurements. Thus, there was no evidence of a significant departure from normality, supporting the use of parametric analysis. A *paired-samples t-test* was subsequently conducted to determine whether students’ fraction numeracy scores differed significantly before and after the use of the “Pecah Rasa” learning medium. The results are presented in Table 4.

Table 4. Paired-Samples t-Test Results

Comparison	Mean Difference	SD	SE	95% CI Lower	95% CI Upper	t	df	p
Pretest – Posttest	-3.387.755	671.327	0.95904	-3.580.593	-3.194.927	-35.324	48	< .001

As shown in Table 4, there was a statistically significant difference between the pretest and posttest scores, $t(48) = -35.324$, $p < .001$. The mean difference of -33.88 indicates that the posttest scores were substantially higher than the pretest scores. The 95% confidence interval for the mean difference ranged from -35.81 to -31.95 and did not include zero, providing further evidence of a difference between the two measurements. Thus, students' fraction numeracy skills after using the "Pecah Rasa" learning medium were statistically higher than those observed before instruction.

To further determine the magnitude of improvement in students' fraction numeracy skills, the pretest and posttest scores were analyzed using N-Gain. The analysis yielded a mean N-Gain score of 0.72489 , which was classified in the high category. This result indicates that the improvement observed after the use of "Pecah Rasa" was not only statistically significant but also represented a high level of normalized learning gain.

Overall, the pretest–posttest and N-Gain results indicate that the use of the "Pecah Rasa" Augmented Reality learning medium was associated with improved students' fraction numeracy skills. The mean score increased from 53.20 to 87.12 , the difference was statistically significant, and the N-Gain was classified as high. These findings suggest that AR visualizations incorporating traditional Central Javanese foods have the potential to support students in learning the addition and subtraction of fractions with like denominators through more concrete and contextual representations. Further interpretation of how AR visualization and local cultural contexts may support these outcomes is presented in the Discussion section.

B. Discussion

The "Pecah Rasa" learning medium was developed using the ADDIE model through the stages of analysis, design, development, implementation, and evaluation. During the analysis stage, students were found to experience difficulties in understanding fraction concepts because instruction tended to be abstract and predominantly lecture-based. Students were more likely to memorize problem-solving procedures than to develop a concrete understanding of part-whole relationships. These conditions highlighted the need for learning media capable of bridging abstract fraction representations with more concrete learning experiences. This finding is consistent with Hidayatullah and Zainil (2025), who explained that elementary school students' difficulties in understanding fractions are associated with the abstract nature of the material and the limited use of concrete instructional media.

In response to these needs, the design stage integrated traditional Central Javanese foods as visual contexts for representing fraction concepts. Familiar objects were incorporated to help students connect mathematical concepts with their everyday experiences. The interface was also designed to be simple, engaging, and interactive to accommodate the characteristics of elementary school students. This approach is consistent with Wahyuni (2024), who demonstrated that integrating local culture into instructional media can enhance students' interest and engagement by presenting learning materials through contexts closely related to their daily lives.

During the development stage, the design was transformed into an Android-based Augmented Reality application using Unity and Vuforia with a marker-based tracking system. The medium incorporated AR scanning, instructional materials, student activities, practice exercises, and assessment features. Three-dimensional visualizations of traditional foods enabled part-whole relationships and fraction operations to be represented more concretely and interactively. These characteristics are consistent with Anggiani et al. (2025), who reported that AR can support students' understanding of fraction concepts through directly observable and interactive visual representations. Hasanah et al. (2024) similarly demonstrated that AR technology can support mathematics learning by providing more tangible and engaging visualizations of mathematical concepts.

The validation results indicated that “Pecah Rasa” received evaluations ranging from fairly good to very good. Media expert validation yielded a mean score of 4.8 and was categorized as very good, whereas material expert validation yielded a mean score of 3.0 and was categorized as fairly good, with revisions recommended before testing. These findings suggest that the product demonstrated particular strength in its media-related aspects, while its instructional content required further refinement. Revisions concerning language, navigation, and visualization were therefore important to ensure that the medium was not only technically engaging but also appropriate for students’ characteristics and learning needs. This finding is consistent with Pratama et al. (2024), who emphasized that technology-based learning media should consider content appropriateness, usability, and visual quality.

During the implementation stage, the medium was used in fourth-grade mathematics instruction at SDN Bener 01 Tenganan and SDN Gubug 01. Classroom observations indicated students’ engagement and enthusiasm when using the AR features and exploring visualizations of traditional foods. Teachers also responded positively to the medium because its visual representations supported more concrete explanations of fraction concepts. These observations are consistent with Einsthendi et al. (2024), who reported that the use of Augmented Reality in learning can support student engagement and active participation. In terms of practicality, the medium achieved a score of 81.91% and was categorized as highly practical. This result indicates that the medium could be used appropriately by teachers and students and that its features were relatively easy to operate during instruction.

Regarding effectiveness, students’ fraction numeracy skills improved following the use of “Pecah Rasa.” The mean score increased from 53.20 on the pretest to 87.12 on the posttest. The paired-samples t-test indicated that this difference was statistically significant, $t(48) = -35.324$, $p < .001$, while the mean N-Gain of 0.72489 was classified in the high category. These findings indicate that the use of “Pecah Rasa” was associated with a high level of improvement in students’ fraction numeracy skills within the context of this study. This result is consistent with Putra et al. (2025), who demonstrated that Augmented Reality-based learning media can support elementary school students’ fraction problem-solving skills. Biassari et al. (2024) also reported that contextual learning media for fractions can significantly improve students’ mathematics learning outcomes.

The observed improvement may be related to the characteristics of “Pecah Rasa,” which combines AR visualization with cultural objects familiar to students. Representations of traditional Central Javanese foods allow fractions to be encountered not merely as mathematical symbols and procedures but also as observable part-whole relationships represented through visual objects. Thus, the integration of AR technology and local culture in “Pecah Rasa” has the potential to create more concrete, contextual, and interactive fraction learning experiences. Overall, the findings regarding validity, practicality, and effectiveness suggest that “Pecah Rasa” has potential as an innovative learning medium for supporting elementary school students’ fraction numeracy skills.

IV. CONCLUSION

This study developed “Pecah Rasa,” an Augmented Reality learning medium incorporating traditional Central Javanese foods using the ADDIE model to support elementary school students’ fraction numeracy skills. The medium received a mean validation score of 4.80 from the media expert, categorized as very good, and 3.00 from the material expert, categorized as fairly good and considered feasible for use after revision. In terms of practicality, the medium achieved a score of 81.91% and was classified as highly practical. Following implementation, the mean fraction numeracy score increased from 53.20 on the pretest to 87.12 on the posttest, with a statistically significant difference ($p < .001$) and an N-Gain of 0.72489, classified in the high category. These findings indicate that “Pecah Rasa” demonstrated adequate feasibility and practicality and has the potential to support improvements in fraction numeracy skills through the integration of AR visualization and local cultural contexts. Therefore, “Pecah Rasa” can serve as an alternative concrete, contextual, and interactive learning medium for teaching fractions at the elementary school level.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest, financial or otherwise, that could have influenced the conduct, interpretation, or publication of this study.

AUTHOR CONTRIBUTIONS

Novita Putri Dharmayanti: Conceptualization, Investigation, Product Development, Data Collection, Formal Analysis, Visualization, and Writing – Original Draft. **Dani Kusuma:** Conceptualization, Methodology, Validation, Supervision, and Writing – Review & Editing. Both authors contributed to the interpretation of the findings, critically reviewed the manuscript, and approved the final version for publication.

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES

During the preparation of this manuscript, the authors used generative AI and AI-assisted technologies solely to support language editing, proofreading, and improvements in the clarity and readability of the manuscript. These technologies were not used to generate research data, perform statistical analyses, fabricate references, or determine the findings and conclusions of the study. All AI-assisted outputs were critically reviewed, revised, and verified by the authors. The authors take full responsibility for the accuracy, integrity, and content of the final manuscript.

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