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Comparing STEM-Integrated Problem-Based and Project-Based Learning in Enhancing Critical Thinking Skills of Madrasah Ibtidaiyah Students

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ABSTRACT

Background. Fostering students' critical thinking skills is a paramount objective in modern education. While STEM-integrated approaches like Problem-Based Learning (PBL) and Project-Based Learning (PjBL) are widely endorsed, comparative evidence of their efficacy in unique educational contexts, such as Islamic primary schools (Madrasah Ibtidaiyah), remains scarce.

Purpose. This study aimed to examine and compare the effectiveness of PBL-STEM and PjBL-STEM models in enhancing the critical thinking skills of Madrasah Ibtidaiyah students, and to assess the effects of problem-based learning-STEM and project-based learning-STEM on students' critical thinking skills.

Method. A quasi-experimental study employing a non-equivalent control group pretest-posttest design was conducted with two intervention groups. Data were analyzed using descriptive and inferential statistics.

Results. The findings show that both models positively improved students' critical thinking skills, with PJBL-STEM yielding a higher posttest mean score (84.58; N-Gain = 77.90%) than PBL-STEM (77.68; N-Gain = 66.77%), and the difference was statistically significant (p = 0.035), demonstrating the superior impact of the project-based approach.

Conclusion. In conclusion, while both frameworks demonstrate pedagogical merit, PjBL-STEM exhibits superior efficacy in fostering students' critical thinking. These empirical findings offer crucial pedagogical insights for primary educators optimizing STEM integration within Islamic elementary school curricula.

KEYWORDS

Critical Thinking Skill, Problem-based Learning, Project-based Learning, STEM

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INTRODUCTION

Education is a conscious and planned effort to create a learning atmosphere and learning process that actively enables students to develop their potential (Maharani & Nasution, 2025). Entering the 21st century, globalization has had a significant impact on technological and scientific advancement (Nurullita et al., 2025). To prepare students to face future challenges, they must possess 21st-century skills, commonly known as the 4Cs: Critical Thinking, Creativity, Collaboration, and Communication (Jamil & Murniati, 2025). Effectively integrating these skills into

classroom instruction is essential to equip students with the ability to think critically (Winda Trisnawati & Arini Kumala Sari, 2019).

According to (Berry & Kowal, 2022), critical thinking is a skill that helps students find solutions to problems. Students with strong critical thinking skills tend to be more active and creative in learning (Hariyanto et al., 2022). It allows students to draw conclusions, evaluate various aspects of a problem, and make decisions based on comprehensive analysis (Gürler & Kaplan, 2023; Palavan, 2020). Critical thinking also encourages logical reasoning and helps students avoid accepting information at face value (Mufida et al., 2022).

In primary education, one of the subjects taught is Science and Social Studies (IPAS), an integrated subject combining science and social studies, aimed at helping students understand natural and social phenomena (Nuryani et al., 2023). IPAS plays a significant role in developing students' critical thinking skills (Maharani & Nasution, 2025). Since IPAS deals with real-world issues, it requires analytical, investigative, and communication skills that directly support critical thinking development (Berliana et al., 2024; Rahayu et al., 2025). The persistently low critical thinking skills observed in classrooms are largely due to conventional teacher-centered instruction, which emphasizes memorization over analytical reasoning. More teaching skills than critical thinking abilities. PBL-STEM and PjBL-STEM overcome these cognitive deficiencies through specialised instructional strategies that bridge this gap. PBL-STEM refers to ill-structured real-world situations that students are exposed to, which require them to analyse variables, synthesise information, and produce possible solutions, all of which are components of critical thinking. In comparison, PjBL-STEM increases this cognitive engagement by students frequently designing, building, and testing real-world projects. The integration of STEM in PBL and PjBL drives students to actively implement interdisciplinary knowledge, changing them from passive learners into critical problem solvers. However, the critical thinking ability of students in Madrasah Ibtidaiyah (MI) in Gunungwungkal Subdistrict remains low. Observations show that most teachers still rely on lecture-based instruction and assignments, which leads to passive learning. As a result, students struggle to engage in higher-order thinking or solve complex problems. Participation in class discussions is also low, indicating a lack of confidence and habit in critical engagement.

According to the mid-semester summative assessments in the 2024/2025 academic year, only 42% of students in Gunungwungkal achieved mastery in IPAS, while 58% did not meet the standard. This quantitative underachievement reflects a broader, more systemic deficiency in students' ability to comprehend, analyze, and critically evaluate learning content. The urgency for instructional intervention is further highlighted by comprehensive preliminary investigations. Based on initial classroom observations, it became evident that when students were confronted with open-ended or non-routine questions, they struggled significantly to formulate logical arguments or identify alternative solutions, relying predominantly on rote textbook answers. Furthermore, preliminary interviews with classroom teachers corroborated these findings, with educators reporting a noticeable lack of student initiative and analytical engagement during science lessons. This triangulation of low academic scores and qualitative behavioral deficits demonstrates an urgent need for robust instructional transformation. To break this cycle of passive learning, more interactive and cognitively demanding models are required. One highly recommended pedagogical approach is problem-based learning (PBL), which confronts students with authentic, real-life problems to stimulate analytical reasoning and active learning (Zhao et al., 2023). In this model, teachers act as facilitators who guide students through analyzing problems, applying prior knowledge, and synthesizing solutions (Y. C. Lee, 2025; Mercy et al., 2020). PBL fosters collaborative learning through group discussions, goal setting, information gathering, and reflective problem-solving (Chueh & Kao, 2024). The

effectiveness of PBL is further enhanced when integrated with STEM, allowing students to relate real-life problems to science, technology, engineering, and mathematics (Gusman et al., 2023). STEM, as a multidisciplinary approach, supports critical thinking by encouraging analytical reasoning, investigation, and teamwork (Wiratman et al., 2023; Wulandari & Sari, 2023). According to (Rahmaniar et al., 2022) STEM-integrated PBL provides structured stages that stimulate students' critical thinking throughout problem-solving processes. Several studies support the effectiveness of STEM-integrated PBL. (Langi, 2024) showed that it positively influences students' critical thinking in Newton's laws. (Evalina & Ihsanudin, 2024) found similar results in junior high school students. Likewise, (Situmeang & Sirait, 2023) confirmed its effectiveness in teaching sound waves.

Another recommended approach is Project-Based Learning (PjBL), which emphasizes real-life project creation (Hao et al., 2024; Son et al., 2024). According to (Manasikana et al., 2023) PjBL encourages students to explore and solve problems through hands-on experiences. This model fosters deeper understanding and retention of concepts by connecting theory with practice (Bupu et al., 2025; Sari et al., 2024). With the integration of modern technology and STEM, PjBL becomes even more powerful in supporting creativity and critical thinking (Megawati et al., 2023; Novitasari et al., 2022). Research by (Dhini et al., 2024), (Dewi et al., 2023), and (Munawwaroh et al., 2023) confirm that STEM-based PjBL significantly improves students' critical thinking skills at the elementary level.

Each model has its strengths. PBL empowers students to solve real-world problems, encourages scientific inquiry, self-assessment, and communication (Sitompul, 2021). Meanwhile, PjBL with STEM integration helps students connect concepts, use technology tools, manage time, collaborate effectively, and engage in authentic, contextual learning (Effendi & Yoto, 2024; Lestari et al., 2020; Lina & Amidi, 2023). Although several previous studies have separately confirmed the positive effects of PBL and PjBL integrated with STEM on critical thinking, a significant gap remains in the literature. Most existing studies analyze the implementation of PBL, PjBL, and STEM separately or primarily focus on secondary education. There is a lack of direct comparative studies to determine which of these two models yields better outcomes, particularly in the specific educational context of Madrasah Ibtidaiyah (Islamic elementary schools). Students at Madrasah Ibtidaiyah follow a unique curriculum that combines Islamic subjects and general science. Consequently, direct comparisons are urgently needed to provide evidence-based advice on which STEM framework is more appropriate and beneficial in promoting critical thinking for this particular ecosystem. This study addresses this gap by providing unique empirical insights into the relative effectiveness of PBL-STEM and PjBL-STEM. Both are recommended for fostering critical thinking. This study is novel in that it compares the effects of STEM-integrated PBL and PjBL models on students' critical thinking. The application of both models, especially in the context of Madrasah Ibtidaiyah, remains limited in prior research, making this study valuable in addressing this gap. Based on the background and prior findings, the researcher is motivated to conduct a study entitled: "The Effect of Problem-Based Learning and Project-Based Learning Models Integrated with STEM on the Critical Thinking Skills of Madrasah Ibtidaiyah Students".

RESEARCH METHODOLOGY

This study employed a quantitative approach using a quasi-experimental method with a pretest-posttest non-equivalent control group design (Creswell & Creswell, 2018; Fraenkel et al., 2015). The research involved three groups: two experimental classes and one control class. Experimental Group 1 was treated using the Problem-Based Learning (PBL) model integrated with STEM, Experimental Group 2 used the Project-Based Learning (PjBL) model integrated with STEM, while the control class received conventional instruction consisting of lectures and practice questions.

The population of the study consisted of all fourth-grade students from 11 Madrasah Ibtidaiyah (MI) in Gunungwungkal District, Pati Regency, with a total of 172 students. A purposive sampling technique was used to select three sample schools based on specific criteria, including equal student numbers, implementation of the Merdeka Curriculum, and readiness to support the research. To minimize selection bias and ensure baseline comparability, the three selected schools were randomly assigned to the treatment and control conditions by drawing lots. Furthermore, a one-way ANOVA was conducted on the students' pretest scores prior to the intervention to confirm that there were no significant initial differences in critical thinking skills among the three groups. The final sample included students from MI Tarbiyatus Shibyan (22 students) assigned to Experimental Group 1, MI Thowalib (26 students) assigned to Experimental Group 2, and MI Manbaul Huda (21 students) assigned to the control group. The research instrument was a critical thinking essay test developed based on five indicators from Ennis (2011), namely, simple explanation, basic skills, inference, advanced clarification, and strategies and tactics. Before empirical testing, the instrument underwent a rigorous content and construct validation process. The validation panel consisted of three experts: two university lecturers specializing in science education and one senior primary school teacher. The criteria for item acceptance included alignment with Ennis's indicators, clarity of language, and cognitive appropriateness for fourth-grade students. The test consisted of 15 items that had been validated by experts and empirically tested using Pearson Product-Moment correlation, with all items deemed valid. Reliability was tested using Cronbach's Alpha, resulting in a value of 0.851, which falls into the very high category (Arikunto, 2021; Widodo et al., 2023).

Item analysis included difficulty level and discrimination index. The test included 4 easy items, 8 moderate items, and 3 difficult items. The discrimination index showed that 13 items were categorized as good and 2 as very good (Arikunto, 2021). Assumption testing was conducted using the Shapiro-Wilk test for normality and Levene's test for homogeneity to confirm the appropriateness of using parametric tests. The data analysis framework evaluated the interventions by first assessing pretest scores to establish baseline equivalence, followed by an analysis of posttest scores and normalized gain (N-Gain) to measure the magnitude of improvement (Sukarelawan et al., 2024). Hypothesis testing was conducted using an independent-samples t-test via SPSS version 26 (Ghozali, 2018) to compare the outcomes between the experimental groups. Additionally, to provide a more comprehensive interpretation of the practical impact of the STEM-integrated models, effect size was calculated using Cohen's *d*. This allowed for a standardized measurement of the magnitude of difference between the PBL and PjBL interventions beyond mere statistical significance, and the effectiveness of the learning models was measured using the N-Gain category.

RESULT AND DISCUSSION

Pretest of Critical Thinking Skills

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results and their interpretation, as well as the experimental conclusions that can be drawn**.** Before the treatments were administered, students from all three groups were given a pretest to measure their initial critical thinking skills. The descriptive statistics are presented in table 1.

Table 1. Descriptive Statistics of Pretest Scores in Critical Thinking Skills

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
Pretest PBL-STEM	22	18	49	35.09	10.323
Pretest PjBL-STEM	26	16	49	34.50	10.104
Pretest Konvensional	21	22	51	35.57	8.807

From the table above, it can be seen that the average initial critical thinking scores across the three groups were relatively balanced, ranging from 34.50 to 35.57. This indicates that the students had equivalent baseline abilities, allowing for a fair comparison after the intervention.

Posttest of Critical Thinking Skills

After the treatments, a posttest was conducted to assess the improvement in students' critical thinking skills. The descriptive results are summarized in Table 2.

Table 2. Descriptive Statistics of Posttest Scores in Critical Thinking Skills

Descriptive Statistics					
	N	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Posttest PBL-STEM	22	56	100	77.68	11.273
Posttest PjBL-STEM	26	58	100	84.58	10.723
Posttest Konvensional	21	49	96	68.05	13.658

These results show that all groups experienced an improvement, with the PjBL-STEM group achieving the highest mean score (84.58), followed by the PBL-STEM group (77.68), and the conventional group (68.05). This indicates that both PjBL-STEM and PBL-STEM were more effective than conventional teaching in improving students' critical thinking.

Hypothesis Testing Using an Independent Sample t-test

The results of the independent-samples t-test between the experimental group (PBL-STEM) and the control group (conventional) are presented in Table 3 below.

Table 3. Independent t-test Results between PBL-STEM and Conventional Groups

Independent Samples Test						
		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
Critical Thinking Skill	Equal variances assumed	.975	.329	2.528	41	.015
	Equal variances not assumed			2.516	38.830	.016

The significance value of 0.015 (< 0.05) indicates that there is a significant difference between the two groups.

The second hypothesis test aimed to determine the effect of the Project-Based Learning (PjBL) integrated with the STEM model on students' critical thinking skills. The results of the independent sample t-test between the PjBL-STEM group and the conventional control group are shown in Table 4. Based on the analysis (equal variances assumed), there was a statistically significant difference in critical thinking scores between the two groups, $t(45) = 4.650$, $p < 0.001$. Furthermore, the calculation

of the effect size yielded a Cohen's *d* of 1.36. This indicates a large effect, demonstrating that the implementation of the PjBL-STEM model had a highly substantial practical impact on improving students' critical thinking compared to conventional instruction. The results of the independent sample t-test between the PjBL-STEM group and the conventional control group are shown in Table 4 below.

Table 4. Independent t-test Results between PjBL-STEM and Conventional Groups

Independent Samples Test						
		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
Critical Thinking Skill	Equal variances assumed	1.221	.275	4.650	45	.000
	Equal variances not assumed			4.532	37.445	.000

The significance value of 0.000 (< 0.05) indicates that there is a significant difference between the two groups. The third hypothesis examined whether there was a significant difference in the effectiveness of the Problem-Based Learning (PBL) and Project-Based Learning (PjBL) models integrated with STEM on students' critical thinking skills. Both experimental groups applied different instructional approaches. As shown in Table 5, the independent-samples t-test (equal variances assumed) revealed a statistically significant difference, $t(46) = 2.168$, $p = 0.035$. To understand the magnitude of this difference, an effect size analysis was conducted, resulting in a Cohen's *d* of 0.63. This represents a medium effect, signifying that while both models are effective, the PjBL-STEM approach provides a moderately stronger practical advantage in accelerating students' critical thinking competencies compared to the PBL-STEM model. The results of the independent-samples t-test are shown in Table 5.

Table 5. Independent t-test Results between PjBL-STEM and PBL-STEM Groups

Independent Samples Test						
		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	Sig.	t	df	Sig. (2-tailed)
Critical Thinking Skill	Equal variances assumed	.000	.986	-2.168	46	.035
	Equal variances not assumed			-2.159	43.865	.036

The significance value of 0.035 (< 0.05) indicates a statistically significant difference in critical thinking skills between students taught using the PjBL-STEM model and those taught using the PBL-STEM model.

N-Gain Test

The N-Gain test was used to measure the effectiveness of each instructional model in improving students' critical thinking skills, based on the normalized gain between pretest and posttest scores. The results of the N-Gain test for each group are presented in Table 6.

Table 6. N-Gain Test Results of Critical Thinking Skills

Descriptive				
	Class		Statistic	Category
NGain_Persen	PBL-STEM	Mean	66.7681	Moderately Effective
	PjBL-STEM	Mean	77.9002	Effective
	Conventional	Mean	52.1627	Less Effective

Based on the table above, the Project-Based Learning (PjBL) integrated with the STEM model demonstrated the highest improvement in critical thinking skills, falling into the effective category. The Problem-Based Learning (PBL) integrated with the STEM model was categorized as moderately effective, while the conventional instruction was found to be less effective.

The Effect of the Problem-Based Learning Model Integrated with STEM on Students' Critical Thinking Skills

The study revealed that students taught using the STEM-integrated Problem-Based Learning (PBL-STEM) model experienced a significant improvement in critical thinking skills. The posttest mean score of the PBL-STEM experimental group was 77.68, higher than that of the control group, which scored 68.05. The independent sample t-test showed a significance value of 0.015 (< 0.05), indicating a statistically significant difference between the two groups. Moreover, the N-Gain for the PBL-STEM group was 66.77%, categorized as moderately effective.

The PBL-STEM model was implemented through five structured phases: problem orientation, student organization, investigation, presentation of results, and evaluation. For example, during a me and my needs topic, students were involved in real-life scenarios such as budgeting within financial constraints. These activities stimulated students' curiosity and required critical thinking from the start, aligning with (Sudarti, 2024), who emphasized the importance of contextual problem orientation in fostering critical thinking readiness. Students were grouped heterogeneously, promoting collaboration and independent inquiry. In a lesson on how I fulfill my needs, students collaboratively explored the evolution from bartering to digital payment systems (QRIS), aligning with (L. Zhang & Ma, 2023), who highlighted the role of structured group projects in encouraging active, collaborative investigation.

In the investigation phase, students engaged in interdisciplinary analysis, for instance, on the topic of buying and selling activities as a way to meet needs, analyzing price fluctuations, comparing distribution tools, and proposing logistics solutions. These activities enhanced systematic thinking and decision-making based on data, supporting findings by (Yuniar et al., 2022).

When presenting their findings, students practiced logical argumentation and active listening. This phase strengthened reasoning and self-confidence, consistent with (Ardyanti & Rezania, 2024), who noted that presenting results in PBL fosters logical communication. The final phase, evaluation and reflection, allowed students to internalize their learning process, supported by interactive quizzes and teacher feedback, as emphasized by (Yu & Zin, 2023). Theoretically, the findings align with constructivist approaches that emphasize knowledge-building through active learning (Wiraningtyas, 2024), and cognitivism, which highlights the role of thinking processes in knowledge construction (Shifa et al., 2025). Prior studies, such as those by (Hasanah et al., 2021) and (Nurazmi & Bancong, 2021), also support the effectiveness of STEM-based PBL in enhancing critical thinking.

The Effect of the Project-Based Learning Model Integrated with STEM on Students' Critical Thinking Skills

The study also showed that students taught using the STEM-integrated Project-Based Learning (PjBL-STEM) model achieved significantly higher critical thinking improvements compared to the control group. The posttest mean of the PjBL-STEM group was 84.58, while the control group scored 68.05. The significance value of 0.000 (< 0.05) confirmed a significant difference. The N-Gain of 77.90% categorized the model as effective.

PjBL-STEM was implemented through six phases, using contextually relevant projects such as creating a needs pyramid, designing a poster about the history of money using the Canva application, and building a diorama that illustrates economic activities during extreme weather conditions. These projects naturally integrated science, technology, engineering, and mathematics, deepening students' engagement and understanding. The initial phase encouraged students to generate essential questions based on real-life issues, such as economical shopping strategies, reinforcing findings by (M. Y. Lee & Lee, 2025) on the importance of contextual driving questions.

During project planning, group discussions and teacher clarification were key in preventing misconceptions (Uyen et al., 2023). Project monitoring allowed for technical and conceptual guidance, increasing students' content understanding and involvement (Gopang et al., 2023). In presenting final products, students logically articulated their ideas and defended them in front of peers and teachers. This developed critical thinking and communication skills (W. Zhang et al., 2024). Final evaluations, conducted through group reflections, helped students identify strengths and weaknesses throughout the project (Elsayary, 2021).

From a theoretical perspective, PjBL-STEM aligns with constructivism through real-world learning experiences (Sugrah, 2020), and with cognitivism by encouraging higher-order thinking such as analysis and evaluation (Shifa et al., 2025). These findings are consistent with (Dewi et al., 2023), (Wati et al., 2024), and (Siadah et al., 2024), who reported significant critical thinking gains through STEM-PjBL. Mufitdah et al. (2024) also found a notable increase from a pretest score of 43.36 to a posttest score of 87.17 (N-Gain = 77%).

The Difference in the Effect of Project-Based Learning Model Integrated with STEM on Students' Critical Thinking Skills

Comparatively, PjBL-STEM yielded better outcomes than PBL-STEM. The posttest mean score of the PjBL-STEM group was 84.58, compared to 77.68 for the PBL-STEM group. The t-test showed a significance value of 0.035 (< 0.05), indicating a significant difference. The N-Gain for PjBL-STEM (77.90%) was categorized as effective, whereas PBL-STEM (66.77%) was only moderately effective. PBL-STEM emphasizes logical reasoning and problem-solving through structured reflection and interdisciplinary analysis (Hasanah et al., 2021), while PjBL-STEM highlights hands-on application through product creation, engaging both mental and physical activities (Hsiao et al., 2024). These differences reflect the models' orientation: PBL-STEM focuses on reasoning, while PjBL-STEM emphasizes real-world application and creativity.

Students in the PjBL-STEM group were more enthusiastic and responsible, contributing to greater development in critical thinking (Lestari et al., 2020). The model proved highly relevant for IPAS instruction due to its integration of analysis, practice, and communication. These results align with (Hidayati & Wulandari, 2024) and Hidayati (2020), who confirmed the superior impact of PjBL over PBL on students' critical thinking.

The results of this study demonstrated that students in the PjBL-STEM group achieved a higher mean score in critical thinking compared to those in the PBL-STEM group, accompanied by a

medium effect size ($d = 0.63$). In educational research, an effect size of this magnitude is considered practically significant, as it surpasses the typical hinge point of 0.40 for observable student achievement impacts(Hattie, 2009). The statistical superiority of the PjBL-STEM model can be attributed to its product-driven and iterative nature. While PBL-STEM successfully stimulates critical thinking through complex, open-ended problem analysis, PjBL-STEM extends this cognitive process by requiring students to physically construct, test, and refine tangible prototypes. According to (Capraro et al., 2013) , the hands-on, engineering design process inherent in project-based STEM environments continuously compels students to engage in higher-order cognitive processing. Furthermore, (Lou et al., 2017) assert that the iterative trial-and-error phases in creating real-world STEM projects foster deeper analytical engagement and knowledge retention. This aligns with the findings of our study, where the tangible output requirement of PjBL-STEM provided students with more concrete opportunities to apply and evaluate their critical thinking skills compared to the purely investigative nature of PBL-STEM.

CONCLUSION

The Problem-Based Learning (PBL) and Project-Based Learning (PjBL) models integrated with STEM have been proven to positively influence the critical thinking skills of Madrasah Ibtidaiyah students. The class that implemented the PBL-STEM model showed a significant improvement in post-test scores compared to the control class (significance value $0.015 < 0.05$), with an N-Gain score of 66.77%, categorized as moderately effective. Meanwhile, the PjBL-STEM model had a greater impact, with a significance value of $0.000 < 0.05$ and an N-Gain score of 77.90%, which falls into the "effective" category. In addition, there was a significant difference in the effects of the two models, as indicated by the results of the independent-samples t-test, which showed a significance value of $0.035 < 0.05$. This indicates that the PjBL-STEM model is more effective than the PBL-STEM model in improving students' critical thinking skills. This study was limited to fourth-grade students and the IPAS subject; further research is recommended at different grade levels or subjects to test the generalizability.

DECLARATION OF AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the author(s) used Grammarly to structure of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as necessary and took full responsibility for the content of the publication.

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AUTHORS' CONTRIBUTION

Author 1: Research design; Methodological guidance; Manuscript writing;
Author 2: Research design; Data collection; Data analysis; Manuscript writing.
Author 3: Methodological guidance; Research supervision; Manuscript review.

DECLARATION OF COMPETING INTEREST

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

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