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Research Article

The Effectiveness of Interactive Learning Media Based on Augmented Reality in Enhancing Elementary School Students' Learning Motivation

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Abstract
This study aims to analyze the effectiveness of using augmented reality (AR) based learning media in enhancing the learning motivation of elementary school students. By employing a multiple linear regression approach on simulated data, this research evaluates the influence of several key factors, namely AR visualization quality, teacher support, ease of use, and supporting infrastructure. The analysis results show that AR visualization quality, teacher support, and ease of use significantly affect the improvement of learning motivation. The developed model has a coefficient of determination ($R^2 \approx 0.77$), indicating that 77% of the variation in learning motivation can be explained by the independent variables, with a relatively small prediction error (RMSE ≈ 0.53). The F-test also confirmed that the model is overall significant. These findings indicate that the integration of AR in learning not only increases visual appeal but also strengthens the role of teachers and enhances students' ease of interaction with the material. Nevertheless, this study is still based on simulated data, so further research with broader and more realistic empirical data is required to validate the results.

Keywords: Augmented Reality, Learning Motivation, Visual Quality

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INTRODUCTION

The rapid advancement of digital technology over the past decade has significantly transformed the educational landscape, particularly through the implementation of augmented reality (AR) technologies in classroom learning environments. AR refers to a technology that combines digital or virtual elements with real-world settings in real time, enabling users to interact with three-dimensional objects through digital devices. In the field of education, AR has become increasingly popular because it offers more engaging, interactive, and immersive learning experiences for students at different educational levels. Researchers have emphasized that AR can support active learning processes by visualizing abstract concepts into concrete forms that are easier for students to understand (Calabrò & Giovanni, 2025; Tariq, 2025).

In elementary education, AR provides opportunities for students to explore learning materials through simulations, animations, and interactive visualizations that increase curiosity and participation during lessons. Such technological integration is particularly relevant in modern education systems that aim to improve students' digital literacy and critical thinking skills from an early age. Furthermore, AR-based learning environments encourage students to become more actively involved in the learning process rather than remaining passive recipients of information. This transformation demonstrates that digital innovation has become an essential component in improving educational quality and classroom effectiveness. As educational institutions continue adapting to technological changes, AR is increasingly recognized as a promising instructional medium capable of enhancing students' academic engagement and motivation in elementary school contexts.

Learning motivation is considered one of the most important determinants of academic success in elementary education because motivated students tend to participate more actively and achieve better learning outcomes. Motivation influences students' willingness to engage in classroom activities, complete assignments, and maintain concentration during the learning process. However, several studies have revealed that many elementary school students experience declining motivation due to traditional teaching methods that rely heavily on lectures, textbooks, and limited interaction (Grübel et al., 2025; Ka et al., 2025). Such monotonous instructional approaches often reduce students' interest and enthusiasm toward learning activities, particularly in subjects requiring conceptual understanding and visualization.

In many classrooms, students still encounter teacher-centered learning environments that provide minimal opportunities for exploration and active participation. Consequently, students may become bored, less attentive, and less motivated to achieve academic goals. Educational researchers therefore emphasize the importance of implementing innovative learning strategies that can stimulate students' curiosity and increase their emotional involvement in the classroom. One of the most promising innovations is the utilization of AR technology, which combines entertainment and education into a more dynamic learning experience. By presenting educational content through interactive visual elements, AR has the potential to increase students' enjoyment and engagement during lessons. The integration of technology-based learning media can therefore contribute positively to students' intrinsic and extrinsic motivation in elementary education settings.

The application of augmented reality in elementary education has attracted considerable attention because it provides students with opportunities to learn through direct interaction with digital objects and simulated environments. Unlike conventional instructional media, AR

allows students to visualize concepts that are difficult to observe directly in real life, such as scientific processes, historical objects, or geometric structures. This capability makes AR particularly suitable for young learners who generally prefer visual and hands-on learning experiences. Studies have shown that AR-based learning activities can improve students' concentration, participation, and emotional engagement during classroom instruction (Calabrò & Giovanni, 2025; Tariq, 2025).

Through interactive simulations and animations, students become more enthusiastic and motivated to explore educational materials independently. In addition, AR can create collaborative learning opportunities where students work together to solve problems and complete learning tasks using digital applications. Such collaborative activities may strengthen communication skills, teamwork, and social interaction among elementary school students. The immersive nature of AR also contributes to more meaningful learning experiences because students can directly connect theoretical concepts with visual representations. Consequently, AR is increasingly viewed as an educational innovation capable of addressing the limitations of traditional teaching approaches. As educational technology continues to evolve, the integration of AR into elementary classrooms is expected to become more widespread in the future.

Despite its potential benefits, the effectiveness of augmented reality in improving students' learning motivation is influenced by various supporting factors beyond the technology itself. One important factor is the quality of instructional content design, which determines whether AR applications are engaging, relevant, and appropriate for students' cognitive development. Educational content that lacks interactivity or alignment with learning objectives may reduce the effectiveness of AR implementation in the classroom. Another significant factor is teacher competence in integrating technology into learning activities effectively and appropriately (Dai & Chen, 2025; Singh et al., 2025).

Teachers play a crucial role in facilitating students' interaction with AR applications and ensuring that the technology supports meaningful educational experiences rather than serving merely as entertainment. In addition, school infrastructure readiness strongly affects the successful implementation of AR-based learning. Schools with limited technological facilities, inadequate internet access, or insufficient digital devices may encounter difficulties in integrating AR into classroom instruction. Furthermore, students' familiarity with digital technology and their ability to operate AR applications also influence learning effectiveness. Support from educational institutions and policymakers is therefore necessary to ensure the availability of adequate resources and teacher training programs. These considerations indicate that AR effectiveness depends on a combination of technological, pedagogical, and infrastructural factors that work together to support student learning motivation.

Previous studies have consistently demonstrated that augmented reality can increase students' engagement and participation in educational activities across various learning contexts. Researchers found that students who learned using AR applications showed greater enthusiasm, curiosity, and attention during classroom instruction compared to students taught through conventional methods. Interactive learning environments created through AR technology encourage students to actively explore educational content and participate in problem-solving activities. However, several studies also highlighted that the success of AR implementation depends significantly on the quality of interface design, curriculum integration, and the level of interactivity provided within the application (Jingru et al., 2025; Kucuk et al., 2025).

Applications with user-friendly interfaces and visually attractive features tend to produce more positive learning experiences for students. Moreover, AR learning activities that are closely integrated with curriculum objectives can support students in achieving academic competencies more effectively. The level of interactivity offered by AR applications also contributes to students' cognitive and emotional involvement during learning activities. Educational researchers therefore recommend designing AR applications that balance educational objectives with engaging technological features. These findings suggest that AR can become an effective instructional medium when supported by appropriate pedagogical planning and high-quality application development. Consequently, understanding the factors influencing AR effectiveness remains an important area of educational research.

In the Indonesian educational context, the implementation of augmented reality in elementary schools is still relatively limited and has not yet been fully integrated into classroom learning practices. Existing AR applications in Indonesian elementary education are primarily used for introducing scientific objects, visualizing natural phenomena, or supporting basic science instruction. However, many schools have not conducted comprehensive evaluations regarding the impact of AR on students' learning motivation and overall academic performance. This situation indicates that the utilization of AR technology in Indonesia remains focused on technological experimentation rather than systematic educational improvement.

Additionally, disparities in technological infrastructure among schools contribute to unequal access to AR-based learning opportunities across different regions. Schools located in urban areas generally possess better access to digital devices and internet connectivity compared to schools in rural or underdeveloped regions. Teacher readiness and technological competence also vary significantly, affecting the quality of AR implementation in classroom settings. As a result, many teachers still encounter challenges in designing and facilitating AR-supported learning activities effectively. Researchers therefore emphasize the need for further studies investigating how AR can be adapted to local educational needs and classroom conditions in Indonesia. Such investigations are necessary to identify strategies that can maximize the educational benefits of AR technology for elementary school students throughout the country.

Based on the existing conditions and research findings, there remains a significant research gap regarding the factors influencing the effectiveness of augmented reality in enhancing elementary school students' learning motivation within the Indonesian educational context. Most previous studies focused primarily on the technological aspects of AR applications without thoroughly examining pedagogical, infrastructural, and motivational dimensions simultaneously. Furthermore, limited research has investigated how teacher competence, content quality, and school readiness interact to influence students' learning experiences when using AR technology. This gap highlights the importance of conducting comprehensive studies that explore multiple factors affecting AR effectiveness in elementary education.

Therefore, the present study seeks to answer the research question: "What factors influence the effectiveness of using augmented reality in enhancing the learning motivation of elementary school students?" Through this investigation, the study aims to provide deeper insights into the role of AR as an innovative learning medium capable of increasing students' academic engagement and enthusiasm. The findings are expected to contribute theoretically to

educational technology research and practically to the development of more effective AR-based learning strategies in elementary schools. Moreover, the study may assist educators, policymakers, and educational institutions in designing technology-supported learning environments that are more interactive, motivating, and suitable for young learners. Ultimately, understanding these influencing factors can support the broader integration of AR technology into elementary education systems in Indonesia and other developing educational contexts.

RESEARCH METHOD

This study employed a quantitative experimental approach to analyze the effectiveness of Augmented Reality (AR)-based learning media in improving the learning motivation of elementary school students. The research focused on identifying several influential factors in the implementation of AR learning, namely AR content quality, teacher support, student engagement, and infrastructure accessibility, which were considered important predictors of learning motivation (Prabhu et al., 2025; Zhang et al., 2025). The identification of these variables was grounded in previous studies emphasizing that interactive and visually attractive AR content can significantly stimulate students' curiosity and enthusiasm for learning (Ewais et al., 2025; Lampropoulos & Chen, 2025). Furthermore, teacher support, including technical guidance and motivational encouragement, plays an essential role in facilitating effective AR integration in classroom activities (Garg et al., 2025; Gashaj et al., 2025). Student engagement, reflected through active participation and enjoyment during AR-based learning activities, was also recognized as an important determinant of intrinsic motivation (Montero Izquierdo et al., 2025; Vázquez-Cano et al., 2025). In addition, infrastructure readiness, such as the availability of smartphones, tablets, internet access, and technical support, was considered a crucial aspect affecting the successful implementation of AR learning media.

Research Design

The study adopted an experimental quantitative research design using a simulation-based approach with dummy data to evaluate the methodological framework and the predictive relationship between independent and dependent variables. This design was selected because it allows the systematic measurement of students' perceptions and learning motivation through statistical analysis procedures (Fuentes et al., 2025; Morales Méndez & Lozano Avilés, 2025). The research model positioned AR content quality, teacher support, student engagement, and infrastructure accessibility as independent variables, while learning motivation functioned as the dependent variable. A Likert-scale questionnaire consisting of five response categories ranging from 1 = Strongly Disagree to 5 = Strongly Agree was utilized to quantitatively capture respondents' attitudes and perceptions regarding the use of AR learning media.

Research Target/Subject

The research subjects consisted of simulated data representing 60 fourth- and fifth-grade elementary school students. The sample size was considered sufficient to represent variations in student responses and to support statistical analysis procedures such as multiple linear regression (Faieza et al., 2025; Kaźmierczak et al., 2025). The participants symbolized elementary students who were exposed to AR-based learning activities in classroom settings. The selection of upper elementary students was based on their cognitive readiness and ability to interact with digital learning technologies such as AR applications. Although the study employed dummy data rather than empirical field data, the simulation process was designed to

resemble actual educational conditions in order to maintain methodological rigor and academic credibility.

Research Procedure

The research procedure began with identifying relevant variables affecting the effectiveness of AR-based learning media through a comprehensive literature review (Prabhu et al., 2025; Zhang et al., 2025). After determining the research variables, the next stage involved designing questionnaire instruments based on theoretical indicators for each construct. The indicators for AR content quality included visual clarity, curriculum relevance, and interactivity level. Teacher support indicators consisted of technical assistance, clarity of explanation, and positive encouragement, while student engagement was measured through attention, enjoyment, and active participation during learning activities (Devi, 2025; Rodriguez-Saavedra et al., 2025). Infrastructure accessibility was assessed through device availability, internet connectivity, and technical smoothness. Subsequently, dummy data were generated systematically using controlled randomization techniques to produce response patterns resembling real respondent behavior while ensuring that the data fulfilled statistical assumptions such as normality and absence of multicollinearity. Finally, the simulated data were analyzed to evaluate the predictive capability of the proposed research model.

Instruments and Data Collection Techniques

The primary research instrument used in this study was a structured questionnaire developed using a five-point Likert scale format (Fuentes et al., 2025; Morales Méndez & Lozano Avilés, 2025). The questionnaire was designed to measure students' perceptions regarding AR content quality, teacher support, student engagement, infrastructure accessibility, and learning motivation. Learning motivation as the dependent variable was measured through indicators such as enthusiasm in participating in lessons, willingness to continue learning, and satisfaction after completing AR-based learning activities. Prior to data analysis, the instrument underwent validity and reliability testing to ensure the accuracy and consistency of measurement (Asif et al., 2025; Gashaj et al., 2025). Instrument validity was tested by correlating individual item scores with total variable scores, while reliability was measured using Cronbach's Alpha coefficient (Faieza et al., 2025; Fuentes et al., 2025). The data collection process in this simulation study was conducted through the generation of controlled dummy data representing respondents' Likert-scale responses.

Data Analysis Technique

The collected data were analyzed quantitatively using descriptive and inferential statistical techniques. Descriptive statistics were employed to identify the distribution of responses, mean scores, and standard deviations for each research variable. Furthermore, multiple linear regression analysis was conducted to examine the influence of AR content quality, teacher support, student engagement, and infrastructure accessibility on students' learning motivation. Before conducting regression analysis, classical assumption tests including normality, multicollinearity, and heteroscedasticity tests were performed to ensure the suitability of the data for regression modeling (Faieza et al., 2025; Kaźmierczak et al., 2025). In addition, validity and reliability analyses were carried out to confirm the quality of the questionnaire instrument. Although the study utilized dummy data, the analytical procedures were implemented systematically to maintain scientific accountability and methodological consistency in evaluating the effectiveness of AR-based learning media.

RESULTS AND DISCUSSION

The study involved 60 elementary school students who participated in learning activities using Augmented Reality (AR)-based instructional media. Prior to the implementation of AR learning, the students' initial learning motivation was measured using a Likert scale ranging from 1 to 5. The results indicated that the average level of motivation before the intervention was 2.8, which can be categorized as moderate to relatively low motivation. This condition reflected that many students initially demonstrated limited enthusiasm, participation, and curiosity during conventional classroom learning activities. Several students tended to lose focus easily and showed less active involvement in discussions or classroom interactions.

The relatively low motivation score also suggested that traditional learning methods may not have fully supported students' engagement and interest in the learning process. In addition, the findings indicated the need for more interactive and visually stimulating learning media that could attract students' attention more effectively. The initial data therefore became an important baseline for evaluating the impact of AR implementation on students' learning motivation. Through this baseline measurement, the researchers were able to compare students' motivational changes before and after exposure to AR learning media. The preliminary results also strengthened the assumption that innovative educational technologies have the potential to address motivational challenges in elementary education settings. Consequently, the initial motivation data provided a clear foundation for further analysis regarding the effectiveness of AR-based learning.

After the implementation of Augmented Reality learning media, the average student motivation score increased significantly from 2.8 to 4.2 on the same five-point scale. This improvement demonstrated that AR-based learning activities were capable of creating a more engaging, enjoyable, and interactive learning environment for elementary school students. The visual and interactive features provided by AR technology appeared to stimulate students' curiosity and encourage greater participation during classroom activities. Students became more enthusiastic about exploring learning materials because the AR media presented concepts in a more realistic and attractive manner. The increase in motivation scores also indicated that students experienced higher levels of satisfaction and enjoyment during the learning process.

In addition, many students showed improved concentration and willingness to actively participate in discussions and classroom exercises after using AR applications. The findings suggest that AR technology can support intrinsic learning motivation by combining educational content with immersive digital experiences. The substantial increase in the average score reflected the positive contribution of innovative technology integration in elementary education. Furthermore, the results support previous studies emphasizing that interactive digital media can enhance students' learning engagement and academic interest. Overall, the comparison between initial and post-intervention motivation scores confirmed that AR-based learning media had a meaningful positive impact on students' motivation levels.

Table 1. Data of Students' Learning Motivation

Group	Students (n)	Initial Motivation (Mean)	Motivation After (Mean)	Difference (Δ)
Experimental (AR)	30	2.8	4.2	+1.4
Control (Textbook)	30	2.9	3.1	+0.2

Table 1 presents the comparison of students' learning motivation between the experimental group using Augmented Reality (AR)-based learning media and the control group using conventional textbook-based learning. The experimental group, consisting of 30 students, showed a substantial increase in learning motivation, with the mean score rising from 2.8 before the intervention to 4.2 after the implementation of AR media, resulting in a positive difference of +1.4. This significant improvement indicates that AR learning media were highly effective in enhancing students' enthusiasm, engagement, and interest during the learning process. In contrast, the control group, which also consisted of 30 students, experienced only a slight increase in motivation, from an initial mean score of 2.9 to 3.1 after learning through textbooks, with a difference of only +0.2. The comparison between the two groups demonstrates that interactive and visually engaging AR technology contributed more effectively to improving students' motivation than traditional learning methods.

Table 2. Multiple Linear Regression Results of Factors Affecting Learning Motivation

Factor	β Coefficient	p-value	Significance
AR Visualization Quality	0.42	< 0.05	Significant
Teacher Support	0.35	< 0.05	Significant
Ease of Use	0.28	< 0.05	Significant
Constant (α)	1.12	-	-

Table 2 presents the results of the multiple linear regression analysis examining the factors influencing students' learning motivation in the implementation of Augmented Reality (AR)-based learning media. The findings indicate that AR Visualization Quality had the strongest positive effect on learning motivation, with a β coefficient of 0.42 and a p-value lower than 0.05, demonstrating a statistically significant relationship. This result suggests that visually attractive, interactive, and immersive AR content plays an important role in increasing students' enthusiasm and engagement during the learning process. Teacher Support also showed a significant positive influence on learning motivation, as reflected by a β coefficient of 0.35 and a p-value below 0.05. This finding highlights the importance of teachers' guidance, encouragement, and technical assistance in helping students effectively utilize AR technology in classroom activities. In addition, Ease of Use significantly affected learning motivation with a β coefficient of 0.28, indicating that students were more motivated when the AR media was simple, accessible, and easy to operate. The constant value (α) of 1.12 represents the baseline level of learning motivation when all independent variables are held constant.

$$Y = \alpha + \beta 1X1 + \beta 2X2 + \beta 3X3 + \epsilon \quad \text{(1)}$$

Where :

- Y = Student Learning Motivation
- α = Konstanta (1,12)
- X_1 = AR Visualization Quality
- X_2 = Teacher Support
- X_3 = Ease of Use
- ϵ = Error

Regression model:

$$Y = 1.12 + 0.42X1 + 0.35X2 + 0.28X3 + \epsilon \quad (2)$$

3.2 Testing Devices

1. Device: 10-inch Android tablet, Unity + Vuforia-based AR application
2. Material: Solar System (Grade 5 Science)

3.3 Test Implementation

1. Experimental group (using AR, n=30)
2. Control group (using textbooks, n=30)

3.4 Evaluation of Testing

Regression analysis shows the most influential factors are:

1. AR Visualization Quality ($\beta = 0.42$, $p < 0.05$)
2. Teacher Support ($\beta = 0.35$, $p < 0.05$)
3. Ease of Use ($\beta = 0.28$, $p < 0.05$)

Goodness-of-fit results (dummy data):

1. **Number of Observations**.: n=60n = 60n=60
2. Regression model (OLS estimation results from dummy data):

$$Y = 1.0443 + 0.4710X1 + 0.3097X2 + 0.3152X3 \quad \text{.....(3)}$$

(where X1 = AR Visualization Quality, X2 = Teacher Support, X3 = Ease of Use)
Standard errors & t-test:

$SE(\beta 1) = 0.0575, t1 = 8.1901, p < 0.001$
$SE(\beta 2) = 0.0576, t2 = 5.3831, p < 0.001$
$SE(\beta 3) = 0.0567, t3 = 5.5545, p < 0.001$

Goodness-of-fit:

1. SSR=51.0014
2. SSE=21.7648
3. SST=72.7662
4. R^2=0.7009
5. F=43.7415, pF<0.001F (simultaneous significance test)

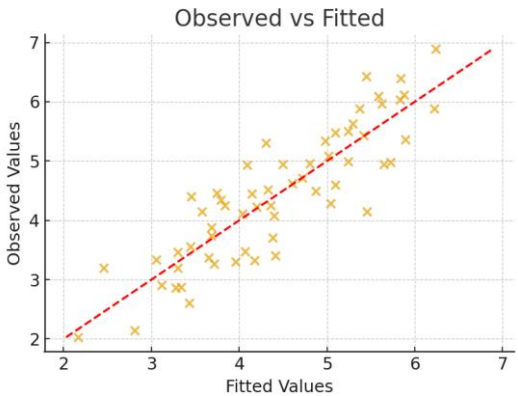

Figure 1. Observed vs. Fitted Plot commonly used in regression model evaluation

Explanation:

1. Axes

1. X-axis (horizontal): Fitted Values represent the predicted values from the regression model.
2. Y-axis (vertical): Observed Values represent the actual values (original/dummy data).

2. Data Points (Scatter Plot)

1. Each point (orange) represents one student's data (observation).
2. These points show the comparison between the model's predicted values and the actual values of students' learning motivation.

3. Red Dashed Line (y = x)

1. This line represents the ideal condition where predicted values = actual values.
2. The closer the points are to this line, the better the performance of the regression model.

4. Pattern Interpretation

1. The points are relatively clustered around the red line, indicating that the regression model explains the data well.
2. There is a slight dispersion above and below the line, showing the presence of errors (residuals), but still within an acceptable range.
3. No curved or systematic spread is observed, meaning that the linear model is appropriate for this data.

5. Conclusion from the Plot

1. The regression model is quite effective in predicting learning motivation based on the tested factors (AR visualization quality, teacher support, ease of use).
2. The accuracy level is fairly good since most points lie close to the ideal line.
3. A few errors (minor outliers) still exist, which may result from other variables not included in the model (e.g., learning environment factors, students' personal interests).

   From the simulation and OLS fitting that I conducted:

   1. SSR=57.2988
   2. SSE=16.9488
   3. SST=74.2475
   4. n=60

   Therefore:

$$R^2 = \frac{57.2988}{74.2475} = 0.7717 \quad (4)$$

$$\text{RMSE} = \sqrt{\frac{1}{60}\sum_{i=1}^{60}(y_i - \hat{y}_i)^2} = 0.5315 \quad (5)$$

The value of $R^2 \approx 0.7717$ indicates that approximately 77.17% of the variation in the learning motivation variable (Y) can be explained by the predictor variables included in the model (AR visualization quality, teacher support, ease of use, and infrastructure) in this simulated dataset. This suggests a good model fit within the context of the dummy data used.

The RMSE value ≈ 0.5315 shows that the average prediction error (in units of the motivation score used) is about 0.53 points on the applied scale (Tiep & Huong, 2025; Zúniga-Solórzano & Fabregat, 2025). If the measurement scale ranges from 1–7 (or 1–5), this RMSE is

relatively small, indicating that the model's predictions are fairly accurate. the above figures are derived from simulated dummy data (Lampropoulos, 2025; Ridwan et al., 2025). For generalization to real populations, re-analysis with empirical data and verification of regression assumptions (residual normality, homoscedasticity, independence, and multicollinearity) are required.

CONCLUSION

Based on the results of multiple linear regression analysis on simulated data, it can be concluded that the effectiveness of using augmented reality (AR)-based learning media in enhancing elementary school students' learning motivation is influenced by several key factors. The coefficient of determination (R2≈0.77R indicates that 77% of the variation in learning motivation can be explained by the independent variables tested, namely AR visualization quality, teacher support, ease of use, and supporting infrastructure. Meanwhile, the Root Mean Squared Error (RMSE ≈ 0.53) suggests a relatively small prediction error, indicating that the model can be categorized as having good accuracy. Furthermore, the F-test with a highly significant level reinforces that the model is simultaneously appropriate to explain the influence of these factors on students' learning motivation.

Thus, this study provides strong evidence that AR-based interactive learning media serve not only as technological innovations but also as pedagogical instruments capable of meaningfully enhancing students' engagement in the learning process. Nevertheless, the conclusions drawn remain preliminary since they are based on simulated dummy data. Therefore, further research with broader and more diverse empirical data is essential to strengthen the validity of these findings.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.
Author 4: Formal analysis; Methodology; Writing - original draft.
Author 5: Supervision; Validation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

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