Contextual interactive animated video media development to promote environmentally relevant chemical equilibrium learning and improve students' motivation

Galuh Clarisa*, Rusly Hidayah

Department of Chemistry Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya, Ketintang Street, Surabaya, 60231, Indonesia

*Corresponding author, email: galuh.22072@mhs.unesa.ac.id

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Abstract
The study was conducted to generate and validate an animated video that will impact students' understanding of chemical equilibrium and its context. They hoped not only that students would grasp the concepts but also that they would show some interest in the material. The researchers designed the research and evaluated the video using the ADDIE model. They selected thirty-four students from the grade and then followed this up with some questions to answer before and after watching the video. The video is not just valid; it is quite good at explaining chemical equilibrium to students. They scored the video 4.57, which means it is valid and has good content. The video was practical when the students viewed it; sixty-two-point nine seven percent of students reported the video as easy to use, and ninety-point eight eight percent considered it very helpful. The video works well because students are interacting with pictures of the environment for information about chemical equilibrium. This encourages students to relate what they are learning to the real world. By researching chemistry concepts, the findings of this research further inform more general strategies to inform students about principles to follow in other areas. Chemical equilibrium is one of the subjects it teaches, but this video uses environmental examples for easy understanding. Students are educated on chemical equilibrium and how important it is, tied to the environment around them.

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1. Introduction

Improvements in information and communication technology have contributed to the increased engagement and efficiency offered by digital learning environments (Haleem et al., 2022; Palacios-Rodríguez et al., 2023). Digital teaching tools allow students to have even more opportunities to engage, create a real impact, and practice much-needed skills in the 21st century (Brkić et al., 2024; Parmini et al., 2023; Hastuti, 2021). Chemistry education provides students with methods from which to comprehend natural phenomena at a molecular level, and relates these concepts to real-life situations (Langitasari et al., 2024). However, chemical equilibrium is still especially difficult for most of the students.

For students to master chemical equilibrium they must embed the concepts across, for example, macroscopic, submicroscopic, and symbolic (Hasanah et al., 2024). They are also expected to interpret equilibrium constants, interpret the graphical data, and comprehend dynamic processes which are not visually identifiable. These complexities commonly lead to confusion as students try to relate abstract concepts to observable phenomena (Herunata et al., 2024). Conventional modes of teaching and resources can either fail to scaffold student understanding or they may not be at all helpful. Thus: interactive and visual learning tools are required to enhance the effectiveness and relevance of chemistry education.

The abstract behavior of chemical equilibrium at the submicroscopic level can pose a challenge for students. Based on empirical research, students have difficulty linking macroscopic, submicroscopic, and symbolic representations, causing errors in the chemical equilibrium (Rahmawati et al., 2022; Deaningtyas et al., 2024; Suparman et al., 2024). A lack of teaching tools that can demonstrate molecular phenomena especially increases these drawbacks. While previous work has shown the impact of visual learning tools, a limited amount of literature has used those tools together with environmental themes, leading to an enhanced conceptual understanding and student engagement.

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There is clearly a need for more innovative educational media that tie science concepts to rich contexts and relate esoteric chemistry to real-world problems. The variety of animation and interactive technologies can be applied to understanding complexities and excite student motivation (Brkić et al., 2024). Digital tools in sustainability education similarly promote greater understanding of the environment by associating scientific principles and the real-life environmental issues (Sánchez-García et al., 2024). Yet, the majority of studies address conceptual knowledge and context, with minimal intersection of animation with environmental material for chemistry teaching.

To address this issue, integrated visualization and environmental context learning tools will be necessary to cultivate comprehension of chemistry and awareness of the environment in students. In the ARCS model, learning motivation includes four key elements: attention, relevance, confidence, and satisfaction. And these factors together predict a student's engagement, perseverance and academic functioning (Keller, 1987). It has been observed that high motivation means higher engagement and understanding with the use of interactive and digital learning media by student among other techniques (Errabo & Ongoco, 2024).

Integrating technology in teaching offers an engaging and meaningful form of stimulation and involvement and inspires the students. The findings suggest that through a mix of motivational aspects embedded within digital study aids, both commitment and deep learning in further detail will be achieved. Animation and interactivity in digital learning tools are also found to help students comprehend theoretical and motivational concepts as research has shown (Fernández et al., 2023; Errabo & Ongoco, 2024). The chemistry education research suggests technology media can stimulate interest and simplify difficult topics (Hidayah et al., 2021).

In terms of the topic of sustainability education, connecting scientific concepts to the reality of environmental problems engenders awareness, engagement with and accountability for addressing challenges (Sunday et al., 2026; Gorito & Morais, 2025; Sánchez-García et al., 2024). Motivation is positively related to academic performance, particularly when learners engage with educational resources (Lutfi et al., 2022). However, the majority of studies have examined visualization-based learning, motivation, and environmental context independently, with only a handful exploring their interplay. Few research studies have demonstrated such animated learning media adapted for integration with the environmental context in order to help students understand concepts and motivate their work within the chemistry domain. In conclusion, this illustrates the importance of using animation-based visuals and environmental content to provide value to the learning experience. In this study, we aim to design and evaluate an environmental context for interactive animated video learning media for its validity, practicality, effectiveness, and motivation enhancement on students' comprehension and motivation in chemical equilibrium.

2. Method

2.1. Research Design Procedure

The research and development (R&D) approach of the study employed the ADDIE model with five phases: Analysis, Design, Development, Implementation, and Evaluation. A one-group pretest posttest design was used to check how well the learning media worked. The ADDIE framework also offered a clear roadmap for implementing the interactive animated video with environmental context. Stages from first analysis to the last evaluation are presented in Figure 1.

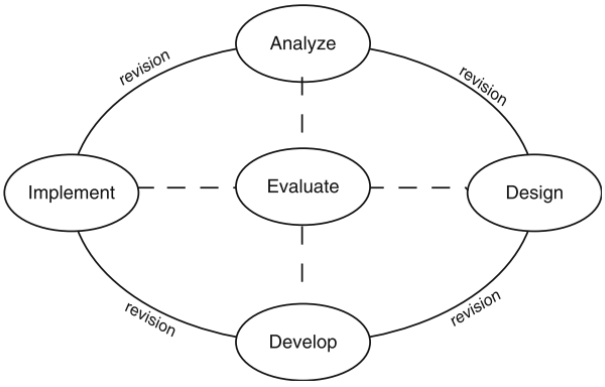


Figure 1. Model ADDIE development

The research procedure was carried out with five basic steps using the ADDIE model, as follows:

a. The analysis phase included the investigation process which required me to define students' problems in chemical equilibrium learning difficulties through classroom observations and teacher interviews. Similarly, curriculum needs and students' profiles were also researched to ensure the suitability of the developed teaching media.

b. The design aspect involved designing learning aims, curricular materials, storyboards, and research instruments. The materials for the learning opportunities were created by integrating environmental settings and real-life situations, thereby facilitating meaningful learning.

c. Development The stage around which the animated video media was developed was based on drawing the prepared storyboard. It was subsequently validated by 3 specialists, namely, two chemistry lecturers and one chemistry teacher. Changes were carried out based on experts' comments.

d. The actual implementation stage included a series of steps in the learning process: (1) administering a pretest to determine the initial conceptual level and learning motivation of students, (2) presentation of the learning objectives, (3) presentation of the animated video-based learning media, (4) guided discussions, and (5) posttest.

e. Validity, practicality, and effectiveness of developed media were evaluated during each phase of the project. Reformations based on the evaluation findings were made accordingly.

2.2. Research Participants and Sampling Techniques

The participants were 34 eleventh-grade students from State Islamic Senior High School 2 Gresik in the 2025/2026 academic year. The participants were selected by purposive sampling because they had studied the prerequisite materials on chemical equilibrium. This study also involved three validators, two chemistry lecturers and one chemistry teacher, in order to determine the validity of the developed media.

2.3. Research Instrument

The developed learning media were evaluated based on three main criteria, as proposed by Nieveen (1999): validity, practicality, and effectiveness. In this study, the research instruments used were carefully designed to collect data on these criteria and to measure students' learning motivation toward the developed media. Each instrument had distinct indicators for each of its study areas. The validation sheet was used to assess the learning media's content and construct validity. At the same time, students' learning motivation was assessed with an ARCS-based questionnaire. Furthermore, a student response questionnaire was used to evaluate the media's practicality. The students' conceptual understanding was evaluated by a pretest–posttest design, and an observation sheet was conducted to observe students' learning activities during implementation. The research instruments, in addition to the indicators, have been summarized in Table 1.

Table 1. Research instrument and indicators

Instrument	Purpose	Indicators	Scale
Validation sheet	Assess content & construct validity	Relevance, accuracy, clarity	Likert (1–5)
Motivation questionnaire	Measure learning motivation	ARCS (Attention, Relevance, Confidence, Satisfaction)	Likert (1–5)
Student response questionnaire	Measure practicality	Ease of use, attractiveness, and usefulness	Guttman (Yes/No)
Pretest–posttest	Measure conceptual understanding	Chemical equilibrium concepts	Score (0–100)
Observation sheet	Observe learning activities	Participation, interaction	Checklist

2.4. Techniques for Data Analysis

The data analysis in this research was carried out to determine the feasibility of the developed learning media by evaluating the validity, effectiveness, and practicality of animated video-based materials on chemical equilibrium concepts.

2.4.1. Validity and Reliability Analysis

Reliability of the learning motivation questionnaire was determined in terms of Cronbach's Alpha, indicating the internal consistency of the instrument. The formula used for this analysis is in Equation 1.

$$\propto = \frac{k}{k-1}\left(1 - \frac{\sum S_i^2}{S_t^2}\right) \quad (1)$$

An instrument is considered reliable when the Cronbach coefficient reaches or exceeds 0.70. The analysis of the learning motivation questionnaire showed a Cronbach's Alpha of 0.80 which confirms high reliability (Tavakol & Dennick, 2011). To examine the validity data, the average score was calculated for each indicator with a Likert scale Table 2.

Table 2. Scale for validation analysis

Scale Score	Validity Category
1	Not Valid
2	Less valid
3	Fairly Valid
4	Valid
5	Very Valid

2.4.2. Practicality Analysis

Data from the response and observation questionnaires were analyzed using a descriptive quantitative approach based on the Guttman scale. Data retrieved from student response questionnaires and observation sheets were used to assess the practicality of the developed learning media. According to the above data, the degree of practicality was classified into several levels, which are not practical, less practical, fairly practical, practical, and very practical, as mentioned in Table 3. For each aspect, the percentage of the score was obtained by the formula according to Equation 2.

$$\text{Percentage responses} = \frac{\text{total score obtained}}{\text{maximum possible e}} \times 100\% \quad (2)$$

Table 3. Criteria for interpreting percentage results

Precentage (%)	Practicality Category
0% - 20%	Not
21% - 40%	Less
41% - 60%	Fairly
61% - 80%	Practical
81%-100%	Very

2.4.3. Effectiveness Analysis

Effectiveness was assessed based on the normalized gain (N-gain) to evaluate (Hake, 1998). Evaluating the improvements in learning outcomes and student motivation. Using the N-gain calculation provided in Equation 3, both pre-assessment and post-assessment scores for learning outcomes and motivation were analyzed. Furthermore, the obtained N-gain values were classified into categories that meet specific criteria proposed in Table 4.

$$\text{N} - \text{gain} = \frac{(\text{Post score}) - (\text{Pre score})}{(\text{Maximum score}) - (\text{Pre score})} \quad (3)$$

Table 4. N-gain value interpretation criteria

N-gain Score	Effectiveness Category
N-gain > 0.7	High
0.3 < N-gain ≤ 0.7	Medium
N-gain ≤ 0.3	Low

A normality test was performed using the Shapiro–Wilk test in order to determine whether data followed a normal distribution. Once data were normally distributed ($p > 0.05$), then we used paired-samples t-test. If it did not meet this requirement, however, a Wilcoxon Signed Rank Test was used instead (Demir, 2022). The statistical analysis criteria of this study are shown in Table 5. A significant difference with $p \leq 0.05$ signifies the difference between pretest and posttest results as statistically important.

Table 5. Statistical analysis criteria

Analysis Statistic	Formula/Tests Used	Criteria	
Normality Test	Shapiro-Wilk Test	p > 0.05	(normal)
		p ≤ 0.05	(not normal)
Paired Sample t-Test	t = (Mean Difference) or (Std. Error Difference)	p > 0.05	(no significant)
		p ≤ 0.05	(significant)
Wilcoxon Signed Rank Test	Based on the pretest and posttest score difference ranking	p > 0.05	(no significant)
		p ≤ 0.05	(significant)

3. Results and Discussion

Herein, this study aims to create interactive animated video learning media in which the environmental context could be included to assist students in better understanding chemical equilibrium and to have improved motivation to learn. The presentation of this topic includes description, theoretical considerations, environmental context integration and the comparison with previous work.

3.1. Analysis Phase

This paper introduces the implementation of media-based interactive animated video learning media through inclusion of environmental context in support of the students' understanding of chemical equilibrium, and motivate the students to learn. It gives an extensive description followed by theoretical discussion, environmental contextualization, and comparative analysis with the available literature. The assessment showed that students found it hard to understand chemical equilibrium, especially in relating macroscopic and microscopic concepts. This finding suggests that students require suitable representation of abstract chemistry topics to attain conceptual scaffolding (Jordan et al., 2026). Additionally, students had the difficulty in relating chemical to environment and context, evidencing that the use of such methods have not been effective in shaping children's minds or skills to learn or to be aware of environment (Chen et al., 2023). Moreover, studies by Estrada et al (2026) indicate that learning environments like interactive and digital environments influence student engagement and concept awareness but only to the extent that learning resources are presented in context to the students.

3.2. Design Phase

The learning media employed integration of visuals and contextualized learning strategies. Videos that portrayed chemical equilibrium at macroscopic and submicroscopic levels aided students in understanding abstract ideas. Supporting content, in other words, was multimedia learning theory, which argued that employing visual representations decreases cognitive load and encourages deeper understanding of challenging material (Kitsantas et al., 2025). Also, adaptive and digital learning systems has been shown to stimulate student interest and learning results through an interactive and personalized learning environment (Yuensook et al., 2026). Moreover, environmental scenarios were embedded in the learning medium in order to link chemical theories with practice so more in-depth integration of course with learning experience could be made (Fan et al., 2024).

3.3. Development Phase

The design of the interactive animated video, including visual animations, audio narration, interactive questions, and contextual content on chemical equilibrium, was intended for learning purposes at the development stage. In turn, the animations were specifically developed to illustrate the interaction of particles at a submicroscopic level and therefore, allow students to correlate macroscopic and molecular insights at lower levels (Jordan et al., 2026). Through this, we hope the developed media will introduce us to certain concepts of chemical equilibrium in an orderly conceptual order of how concentration, temperature, pressure, and catalysts impact the equilibrium systems. The media places high significance on concept, including visual representation of the content and a consistent conceptual stream for understanding shifts of equilibrium through Le Châtelier's principle. Research has shown visual-based learning to lessen the overall cognitive load and improve understanding of concepts among students (Chen et al., 2013).

In the first stage, conceptual, the learning media explain how changes in concentration affect chemical equilibrium. As the concentrations of reactants increase they move equilibrium to the product side so that as much disturbance as possible can be avoided and the higher the product concentration the more the equilibrium will move to the reactants. This concept finds application in biological systems, like gas exchange, where varying concentrations of CO_2 modify equilibrium. Having the ability to contextualize concepts, allow students to relate more complicated chemical equilibrium principles to their own environment- and biology-related phenomena, resulting in deeper insights (Jordan et al., 2026).

When looking at temperature within chemical equilibrants, we're in Stage 2. During this stage, students are also presented with a description of how the direction of shift in the equilibrium is depending on whether the reaction is exothermic or endothermic. Higher temperatures help make the equilibrium possible endothermic, while lower temperatures push it toward exothermic. This theme gets represented well in the Haber method. Temperature will significantly influence the output of an ammonia factory, as shown in the earlier experiment. Additionally environmental consideration is the context of the situation in this case. Therefore, learners can associate theories in the field of chemical equilibrium with sustainability topics more generally (Trevisan et al., 2024).

In a gaseous system, the third stage involves the effects of pressure and volume on equilibrium and is responsible for controlling how it behaves. Here, students have learned that less pressure will cause that equilibrium to shift to the side with more gas particles, and an increase of pressure will mean that the side with

fewer gas particles will prevail. Examples for typical situations (i.e., when the pressure is reduced, dissolved CO_2 opens up freely in carbonated water) demonstrate this. Students benefit from this, as they are reinforced in learning through real-life instances and realizations linking theoretical concepts to empirical findings (Ba et al., 2026).

Stage four emphasizes the function of a catalyst in equilibrium systems. Students are told to see that catalysts act to speed up the forward and backward reactions in equal measure, while not altering the equilibrium state. Instances on the biological level support this idea, where rates of the reaction change without upsetting the equilibrium state (like enzyme activity). It aims to combat misinformation and enhance understanding (Fan et al., 2024).

Overall, the sequence of elements show that the media produced through application are not only visual representations of chemical equilibrium principles, but are systematic and lucid learning models. The inclusion of environments and everyday environments in all stages has helped in meaningful learning as students can identify and link abstract concepts of chemical concepts based on their natural environment. However, this aligns directly with contextualist and sustainability-based learning procedures, one to recognize the broader environmental effects of chemical actions on students.

3.3.1. Validitty

The validation results presented in Table 6 indicate an average score of 4.57, suggesting that the developed learning media satisfies both content and construct validity criteria.

Table 6. Validity data result

Component	Validation Score	Category
Content validity	4.52	Valid
Construct validity	4.66	Valid
Aspect validity	4.54	Valid
Average	4.57	Valid

With content validity, construct validity, and aspect validity as the main categories, Table 5 presents the results of expert judgment for the validation assessment of the created learning media. Overall, all evaluated components were rated as valid (average score = 4.57). These results show that the learning media is properly linked with the learning goals, it is structured and their presentation is of high quality so that they can be implemented in the learning process.

3.3.2. Reliability

The reliability of the learning motivation questionnaire was tested using Cronbach's Alpha, the result is at Table 7.

Table 7. Reliability statistics of the learning motivation questionnaire

Component	Number of Items	Cronbach's Alpha (α)	Category
Attention	2	0.78	Reliable
Relevance	2	0.81	Reliable
Confidence	2	0.83	Reliable
Satisfaction	2	0.80	Reliable
Overall Instrument	8	0.84	Highly Reliable

Table 7 presents the results of the reliability test of the learning motivation questionnaire using Cronbach's Alpha. The obtained reliability coefficient of 0.84 indicates a high level of internal consistency, suggesting that the instrument is reliable for measuring students' learning motivation. In line with this, the questionnaire also demonstrated a Cronbach's Alpha value of 0.80, which further confirms its high reliability (Tavakol & Dennick, 2011).

3.3.3. Practicality

The practicality results presented in Table 8 indicate the average score obtained from observation data.

Table 8. Observation result

Information	(%) Score	Category
Observation questionnaire	62.97	Practical
Response questionnaire	90.97	Very Practical

The assessment results, by different participants of developed media in instruction environments are presented in Table 8. The average score is 62.97%, meaning the media are practical, with most of the learning activities being interspersed into the intended instructional design. Nevertheless, some elements require another effort of refinement for greater effectiveness of implementation. Previous research has shown that interactive and digital learning media increases usability, engagement, and learning experience of students. The student response questionnaire score was 90.88% which was great. The results indicate that in the learning media, students were engaged with the media well and therefore were useful and intuitive in the understanding of chemical equilibrium concepts. The high response of students to the visual aids and context content which makes them more engaged and efficient in learning digital environments, is accountable for the high rate (Ba et al., 2026). The addition of practical applications and real-world examples also helps students to relate abstract chemical concepts to everyday situations (Mediana et al., 2025). Other research demonstrates that user experience can be enhanced with the use of technology and interactive learning environments for better usability, learner motivation, and user cooperation (Granström & Oppi, 2025).

3.3.4. Effectiveness

Effectiveness for the interactive animated video was evaluated through research of the improvement on students' learning outcomes and motivation after its introduction. In particular, student responses and observation results are quite distinct in that while both instruments measure different facets, observations produce an objective measurement of an activity, while student questionnaire captures the learners' perception of the media. The outcomes from both ends are a sign that the developed media are useful and support the process of learning. N-gain value of 0.80 showed a successful outcome of learning, the interactive animated video had high significance in improving students' learning process in chemical equilibrium. Such gains can be attributed to the visualization and interactive effects, which support abstract information processing (Sipahi & Bahar, 2025).

This level of classical completeness (0.94) also indicates that most students passed the minimum mastery requirements. These results also confirm that the produced learning media help to solidify students' knowledge of the core chemical equilibrium phenomena systematically and contextually (García-Hernández et al., 2022). For the study on the learning motivation score, N-gain value was 0.48 (Moderate). This result shows that interactive animated video has a positive effect on the motivation, but not much in contrast to academic accomplishment. These results are consistent with prior research that demonstrated the positive effects of interactive digital learning environments on student engagement and motivation (Yuensook et al., 2026). In addition, the Wilcoxon test revealed a significance level of 0.00 ($p < 0.05$), which meant there is considerable difference of their pretest and posttest scores towards not only learning outcomes, however also the learning motivation.

The results confirmed that created learning media results in the obtained results. Results in supporting prior work in proposing that technology-assisted training and interactive electronic contents can also help facilitate student learning and students' engagement through motivation and sense of connection in learning (García-Hernández et al., 2025). This interactive animated video produced in this workshop had worked well, as it helped the students gain a better content knowledge and motivation. They work by including visualization and context, interactive functions assist students in learning how abstract chemistry concept is connected to context. An increase in learning outcomes is demonstrated by the high N-gain value (Table 9) of 0.80 and an overall class completeness level of 0.94. Motivation for students also increased to moderate proportions. Test score for Wilcoxon ($p < 0.05$) confirmed a significant difference between pre- and post learning conditions.

Table 9. Validation result

Component	Indicator	Result	Category
Learning Outcomes	N-Gain	0.80	High
	Classical Completeness	0.94	Achieved
	Wilcoxon Test (Sig.)	0.00	Significant
Learning Motivation	N-Gain	0.48	Moderate
	Wilcoxon Test (Sig.)	0.00	Significant

3.3.5. Environmental and Sustainability Perspective

Additionally, not only does adding environmental contexts to the developed learning media improve students' awareness, it also reinforces their grasp of chemical equilibrium. The media showcase principles of equilibrium built upon Le Chatelier's principle, such as the importance of concentration, temperature, and pressure, while linking with real-world and environmental contexts. As an example, the Haber process shows that increasing temperature shifts the equilibrium direction of an exothermic reaction to the reactants, resulting in decreased yield of ammonia, although higher temperatures are still employed industrially to speed up reaction rates. This supports student understanding in equilibrium principles and their environmental consequences (e.g., energy usage and emissions) (Trevisan et al., 2024).

The generalisation of concentration can also be related to gas-exchange phenomena, wherein changes in CO_2 concentration affect equilibrium with biological and ecological elements (Mediana et al., 2025). Similarly, students connect more abstract concepts to real-world experiences through the principles of pressure, illustrated through carbonated drinks. These studies illustrate that the produced media support understanding and application of chemical knowledge to environmentally related problems. This observation is consistent with earlier studies that demonstrate the learning contextual and environmental knowledge of students is improved by technology-learning (Ankareddy et al., 2025). Classroom teaching that centers on sustainability also enables students to think critically about the environment in which the chemical processes take place and leads to more educated views on how to solve the problem sustainably (Bataeineh & Aga, 2022). In this respect, the learnt media support conceptual learning as well as sustainability education. More studies should investigate the long-term consequences of the study on students' environmental attitudes.

4. Conclusion

The results clearly indicate that the interactive animated video integrated with environmental contexts demonstrated in this study is valid, practical, and effective in improving conceptual understanding and motivation for learning chemical equilibrium in students. By adding visualization to concrete environmental examples, it helps students to understand abstract concepts (e.g., equilibrium shifts) through the lens of real-life events, like industrial processes, as well as environmental systems. Our results underscore how the study connects concepts of chemistry to teaching and learning processes that promote sustainability. The formulated media not only enhances learning outcomes but enriches student learning with an emphasis on environmental education in that it helps students to make critical assessments of the environmental implications of chemical processes. Accordingly, such work forms a valuable input to the development of context- and environmentally relevant chemistry learning media. However, more studies are needed to investigate how environmental media shape students' long-term environmental attitudes, sustainability awareness, and higher-order thinking skills.

Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data Availability

The datasets generated during and/ or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.

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