JPPIPA 12(1) (2026)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Development of Augmented Reality-Based Scansmart Card Media to Improve Elementary Students' Understanding of Photosynthesis in Support of SDG 4 (Quality Education)

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Received: November 06, 2025
Revised: December 23, 2025
Accepted: February 14, 2026
Published: February 14, 2026

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DOI: 10.29303/jppipa.v12i1.14281

Abstract: This study aimed to develop and evaluate the effectiveness of Augmented Reality (AR)-based Scansmart Card learning media to improve fourth-grade students' understanding of photosynthesis in elementary schools, in line with Sustainable Development Goal 4 (Quality Education). The research employed a Research and Development (R&D) approach using the ADDIE model, consisting of analysis, design, development, implementation, and evaluation stages. The developed media integrates printed cards with AR features accessed through the Assemblr Edu application, presenting interactive 3D visualizations, audio explanations, and quizzes related to photosynthesis concepts. Product validity was assessed by material and media experts, resulting in validity scores of 92 and 95%, respectively, which were categorized as highly valid. Limited field trials were conducted with 30 fourth-grade students at SDN Tlekung 02 Batu using a one-group pretest–posttest design. Data analysis included normality testing using the Shapiro–Wilk test, paired sample t-test, and N-gain analysis. The results indicated that the data were normally distributed and showed a significant difference between pre-test and post-test scores ($t = 6.87$; $p < 0.05$). The average N-gain score was 0.63, categorized as moderate, indicating effective learning improvement. These findings demonstrate that the AR-based Scansmart Card media is valid, feasible, and effective in enhancing students' understanding of photosynthesis and supporting the improvement of elementary science learning quality.

Keywords: Augmented Reality (AR); Elementary school; Photosynthesis; Scansmart card; SDG 4

Introduction

Natural and Social Sciences Education (IPAS) is an integrated subject that combines Natural Sciences (IPA) and Social Sciences (IPS) to support students' holistic understanding of natural and social phenomena (Zahroh et al., 2024). IPAS examines living and non-living components of the universe and their interactions, as well as human life as individuals and social beings interacting with their environment (Riyadi, 2025). Through IPAS learning, students are encouraged to develop curiosity about phenomena occurring around them, which supports their understanding of how the natural world works and relates to human life (Habbah & Sari, 2023). Science education creates human resources who are innovative with excellent soft and hard skills, who are able to compete and overcome various global challenges (Ermiyawati et al., 2025).

This integrated approach aligns with the 2013 Education Policy, which emphasizes cross-subject learning, including the integration of natural and social sciences within IPAS. The implementation of integrated learning aims to help students recognize relationships between scientific and social concepts, enabling them to construct meaningful and comprehensive understanding of their environment (Zahroh et al.,

How to Cite:
Billa, Y. S., & Restian, A. (2026). Development of Augmented Reality-Based Scansmart Card Media to Improve Elementary Students' Understanding of Photosynthesis in Support of SDG 4 (Quality Education). *Jurnal Penelitian Pendidikan IPA*, *12*(1), 797-805. https://doi.org/10.29303/jppipa.v12i1.14281

2024). To support this goal, inquiry-based learning is emphasized in IPAS instruction, as it encourages students to actively explore natural phenomena and construct knowledge through observation and questioning (Lami'ah et al., 2025).

Among the various topics in IPAS, photosynthesis is a core concept that requires in-depth understanding. Through photosynthesis learning, students are expected to understand how plants produce food, identify the components involved, and recognize the benefits of photosynthesis for living organisms. However, photosynthesis is often difficult for fourth-grade students to understand because it involves abstract biological processes that cannot be directly observed, which frequently leads to misconceptions and low learning outcomes (Febriany & Bektiningsih, 2025).

Classroom observations and interviews conducted at SDN Tlekung 02 Batu indicate that photosynthesis learning in fourth grade is still dominated by textbooks, worksheets, and instructional videos from YouTube. These learning resources provide limited visualization of abstract processes, resulting in low student engagement and difficulties in developing clear conceptual understanding. Learning methods that rely heavily on textbooks often make students feel bored and experience challenges in understanding the material.

Learning media plays a crucial role in helping educators convey abstract scientific concepts effectively. Insufficient use of appropriate media can result in students' incomplete understanding of learning materials. With the rapid development of technology, educators are required to be creative and capable of utilizing technological tools that align with students' characteristics and learning needs. One promising innovation is the integration of learning materials with Augmented Reality (AR) technology, which enables interactive and contextual learning experiences (Indra et al., 2022).

Improving students' conceptual understanding through meaningful and technology-supported learning is closely related to the achievement of Sustainable Development Goal 4 (SDG 4), which emphasizes inclusive, equitable, and quality education for all learners (Oktavianatun & Nugraheni, 2024). At the elementary level, quality education requires learning experiences that are interactive, contextual, and aligned with students' cognitive development stages to support deeper understanding and long-term learning outcomes.

In elementary science learning, Augmented Reality can serve as a bridge between abstract concepts and concrete experiences. By presenting photosynthesis processes through interactive 3D visualizations, AR enables students to observe plant structures, components, and internal processes that are otherwise invisible (Juwairiah et al., 2025). Augmented Reality technology integrates virtual objects with real-world environments, allowing learners to experience digital content as if it were physically present through cameras and sensors on electronic devices (Susanto et al., 2022).

In this study, the term *optimizing understanding* refers to efforts to maximize students' mastery of concepts through the use of specific learning media, namely Augmented Reality-based Scansmart Cards. Optimization involves not only improving understanding but also achieving learning outcomes that are more effective, efficient, and meaningful compared to conventional learning approaches (Apriliyanto, 2025).

Previous studies have shown that AR-based learning media have great potential to improve students' conceptual understanding and interest in learning (Hafizah et al., 2025). However, the media developed by previous researchers generally still focus on 3D object visualization and visual presentation of information, without being supported by systematic audio explanations and interactive quizzes for each subtopic. This limitation indicates a research gap in the development of AR-based Scansmart Card media that integrates visual, auditory, and interactive assessment components.

This limitation indicates that students may still have disconnected understanding of abstract scientific concepts, such as photosynthesis. Therefore, it is necessary to develop AR-based learning media that not only displays visual representations but also integrates structured audio explanations and interactive quizzes. This study addresses this gap by developing Augmented Reality-based Scansmart Card that combine 3D visualization, audio narration, and interactive quizzes to optimize fourth-grade students' understanding of photosynthesis and This development is expected to support meaningful science learning and contribute to improving the quality of elementary education in accordance with Sustainable Development Goal 4 (SDG 4).

Method

This study uses the Research and Development (R&D) method with the ADDIE development model. The R&D method was chosen because it is suitable for producing valid, practical, and effective learning products through a process of testing and revision. This model concept is applied to build basic performance in learning and develop a learning product design (Hidayat & Nizar, 2021). The ADDIE model consists of five stages in its application, namely analysis, design,

development, implementation, and evaluation (Arianty et al., 2021). The ADDIE model used includes five main stages, as visualized in Figure 1.

Figure 1. Schematic of the ADDIE model development process flow

This research was conducted at SDN Tlekung 02 Batu, Jl. Raya Tlekung RT 03 RW 06, Tlekung Village, Junrejo District, Batu City.This research involved 30 fourth-grade students and fourth-grade teachers. In accordance with the steps shown in the figure above, development will be carried out in five stages. The first stage is the analysis stage, which involves identifying problems in science learning, student characteristics, and learning media needs. Data was obtained through observation and interviews with fourth-grade teachers and students, which were then used as the basis for product design. The second stage is the design stage, which involves compiling the planning components of the media, including learning objectives, indicators for achieving learning objectives, materials to be included, and media product design using Canva and the Assemblr Edu application. The third stage is the development stage, which is the stage of printing the soft-file design onto print media or physical copies. The product is then verified by subject matter and media experts to assess its validity.

The fourth stage is implementation, namely limited trials, conducted on 30 fourth-grade students at SDN Tlekung 02 Batu. The trials aim to assess the suitability of using the media through student and teacher response questionnaires, as well as evaluating the effectiveness of the product through pre- and post-tests. During the learning process, the media was used in real situations, not only for demonstrations, but the teacher also provided students with Augmented Reality-based scansmart card media on photosynthesis to try and learn independently, while still being accompanied by the teacher. Finally, the evaluation stage, namely the final revision, was carried out to make the product more feasible, practical, and effective as learning media.

Data collection techniques in this study included observation, interviews, questionnaires, tests, and documentation. The tools used in this study included observation sheets, interview guidelines, subject matter expert validation questionnaires, media expert validation questionnaires, teacher response questionnaires, and student response questionnaires. Observation sheets and interviews were used to analyze existing problems and identify solutions for this study. Subject matter and media expert validation questionnaires were used to determine the feasibility of the developed product. This trial was conducted to evaluate the effectiveness of the product by comparing the pretest and posttest results. The pretest results were obtained before learning using Augmented Reality (AR)-based scansmart card media, while the posttest questions were taken from evaluations during the learning process. Both the pretest and posttest consisted of 10 questions, including 5 multiple choice and 5 essay questions. Teacher and student feedback questionnaires were used to determine the responses of teachers and students to the developed product. Documentation in this study included the collection of references from various sources and images during the development and implementation process. In addition, a single group pretest and posttest design was used, namely a pretest conducted before using Augmented Reality (AR)-based smart card media and a posttest conducted after using the media (Gulo & Harefa, 2022).

The data analysis techniques used were qualitative and quantitative. Qualitative analysis was used to analyze data generated from interviews, observations, and suggestions from media and material expert validators. Quantitative data analysis techniques were used Quantitative data analysis techniques were used to analyze the validation questionnaire scores from media and material experts, teacher responses, student responses, as well as pre-tests and post-tests. The results of the data analysis of material expert validation and media expert validation were used to measure the validity of the Augmented Reality (AR)-based Scansmart Card learning media product developed in accordance with Formula 1.

$$\text{Validity Value} = \frac{\text{Score Total}}{\text{Score Max}} \times 100\ \% \quad (1)$$

Table 1. Validity criteria for Augmented Reality (AR)-based Scansmart card products (Ramadani et al., 2025)

Range (%)	Category
81–100	Incredibly Valid
61–80	Valid
41–60	Sufficiently Valid
21–40	Less Reliable
0–20	Not Valid

The assessment results are then categorized according to the criteria specified in Table 1.

Data analysis of student and teacher questionnaire responses was conducted using the Guttman scale with two answer options: "yes" and "no." The maximum total score was 100 with 10 items, each worth 10 points. The questionnaire responses were then analyzed using the Formula 2.

$$\text{Percentage} = \frac{\text{Number of correct answers}}{\text{Total of Score}} \times 100\ \% \qquad (2)$$

Table 2. Criteria for student and teacher responses (Emylia et al., 2025)

Achievement Level (%)	Qualifications	Category
81–100	Very good	Highly recommended
71–80	Good	Worthy
51–70	Not good	Unsuitable
< 50	Very bad	Highly inappropriate

The effectiveness of the Augmented Reality (AR)-based smart card learning media developed was analyzed through student learning outcome data. Students were considered successful or passed if they obtained a score of 75 or more, meeting the Learning Objective Achievement Criteria (KKTP). The final stage of data analysis in this study included several procedures: normality tests to evaluate data distribution, t-tests to compare pretest and posttest scores, and N-gain tests to evaluate the effectiveness of learning media in optimizing fourth-grade students' understanding of photosynthesis material. These steps were carried out systematically to ensure that the conclusions obtained were valid (Diani & Wulandari, 2025). The N-gain calculation used Formula 3.

$$N_{gain} = \frac{\text{Posttest Score} - \text{Pretest Score}}{\text{Maximum Score} - \text{Pretest Score}} \qquad (3)$$

Table 3. Criteria of N- Gain (Abdilah et al., 2024)

N-Gain Value	Category
g > 0.7	High
0.3 ≤ g ≤ 0.7	Moderate
g < 0.3	Low

Result and Discussion

Analysis

The analysis stage aims to identify, in the learning process, namely: problems in science learning; student needs; student characteristics in IPAS learning. After conducting interviews with fourth-grade teachers at SDN Tlekung 02 Batu, it was found that photosynthesis learning in fourth grade currently only uses worksheets and textbooks, and the digital media used is limited to animated videos on YouTube as a medium for delivering material. In the specific context of IPAS learning in elementary schools, photosynthesis material is often difficult for 4th grade elementary school students to understand because it is abstract and involves biological processes that cannot be observed directly. Therefore, there is still a need to develop interactive digital media that makes it easier for students to understand abstract material, such as Augmented Reality (AR)-based scansmart card media. Teachers also mentioned that their students had difficulty understanding abstract science concepts without media. Observations in the classroom showed that during lessons, only a few students actively listened to the teacher at the beginning, and in the middle of the lesson, students became bored and reluctant to learn because they did not understand the abstract material explained by the teacher.

Design

Table 4. Draft Layout Design the Scansmart card photosynthesis

The design stage includes determining the materials, learning outcomes, learning objectives, learning outcome achievement indicators, and media

titles, as well as media creation. The Augmented Reality (AR)-based Scansmart card media design was created with the help of the Canva application, the Assembler Edu application, and Wordwall. The Canva application was used to create the design of the physical Scansmart card illustration, which is represented in Table 4. The Scansmart card developed is titled "Scansmart Card Photosynthesis for Grade IV Elementary School." The Assembler Edu application was used to integrate images, text, audio, and 3D animations to produce an interactive and attractive AR display when scanned or scanned via a mobile phone. The Wordwall application is used to create interactive quizzes that are presented in each discussion topic, tailored to the indicators of learning objectives.

Slide 1 contains the cover, slide 2 contains steps for using the media, slide 3 contains an explanation of the parts of plants that play a role in photosynthesis, slide 4 contains an interactive quiz on the parts of plants that play a role in photosynthesis, slide 5 contains an explanation of the components of photosynthesis, slide 6 contains a true/false quiz on the components of photosynthesis, slide 7 contains an explanation of the photosynthesis process, slide 8 contains a matching quiz on the photosynthesis process, slide 9 contains an explanation of the benefits of photosynthesis for living things, and slide 10 contains a true/false quiz on the benefits of photosynthesis for living things.

Development

Table 5. Specifications for photosynthesis smart card media

Paper Size	13 cm x 18 cm
Paper type	Art Paper
Number of pages	10 Pages
Color	Full color

This stage focuses on transforming the design into a ready-to-use Augmented Reality (AR)-based ScanSmart Card learning medium. The development process includes designing visual card assets that function as AR markers, containing illustrations of plant parts, photosynthesis components, processes, and benefits, equipped with QR codes or special markers that are compatible with the Assemblr Edu platform and tailored to the characteristics of elementary school students. This material is supported by 3D models, AR animations, and audio explanations of photosynthesis content. These elements are integrated into the Assemblr Edu application by connecting markers to interactive 3D objects equipped with features such as rotation, zoom, and audio synchronization. The learning content is adapted to validated teaching modules. The product was designed using Canva and Assembler Edu and printed on 13 cm x 18 cm art paper. With the following specifications is shown in Table 5.

During development, a validity questionnaire was also created to test the product's suitability with expert validators. These validators included media experts and material experts, as shown in Table 6. Based on Table 6, the product assessment by media experts resulted in a total score of 57 out of 60, which is equivalent to 95% and places it in the "highly valid" category. This indicates that the photosynthesis smart card media scans are suitable for testing and are highly suitable for use in elementary schools in the learning process.

Table 6. Validation results by media experts for Augmented Reality (AR)-based smart card media scans for photosynthesis

Indicators	Total Score	Maximum Score	Percentage (%)
Visual appearance and design	15	16	93.75
Ease of use (User Friendly)	10	12	83.33
Integration and interactivity	12	12	100
Media suitability for learning objectives	12	12	100
Creativity and innovation	8	8	100
Value validity result of media expert validation	57	60	95

Table 7. Result of the material expert validation

Indicators	Total Score	Maximum Score	Percentage (%)
Material suitability	15	16	93.75
The truth and completeness of the concept	11	12	91.66
language and presentation	11	12	91.66
Value validity results of material expert validation	37	40	92

The results in Table 7 show that the expert validators' assessment of the developed product content achieved a total score of 37 out of 40, representing 92%. This assessment indicates that the material presented in the Augmented Reality (AR) Photosynthesis-based smart card media is very suitable for use.

Implementation

After the Augmented Reality (AR) Photosynthesis-based scansmart card media passed the validity testing stage, the scansmart card was ready to be tested to determine student response. The implementation involved fourth-grade students at SDN Tlekung 02 Batu and their classroom teachers. Figure 2 shows the implementation of learning using Augmented Reality (AR) Photosynthesis-based scansmart card media.

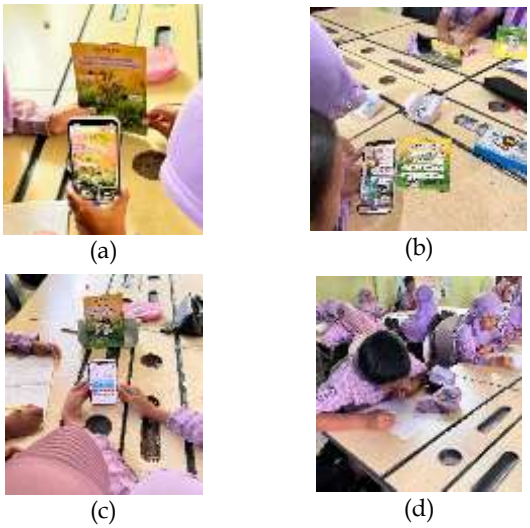

Figure 2. Implementation of learning using Augmented Reality (AR)-based smart scan cards for photosynthesis: (a) AR display of plant parts involved in photosynthesis; (b) AR display of the benefits of photosynthesis for living things; (c) AR display of interactive quizzes; (d) Filling out evaluation questions (post-test)

Table 8. Student responses to the Augmented Reality (AR) photosynthesis-based smart card media

Student Name	Score Total	Percentage %	Category
ANZ	40	100	Very Good
AGAS	35	87.5	Very Good
AAK	37	92.5	Very Good
ADZ	37	92.5	Very Good
AD	40	100	Very Good
AWD	40	100	Very Good
DJP	40	100	Very Good
EAS	40	100	Very Good
EAG	35	87.5	Very Good
FAA	38	95	Very Good
FEDA	40	100	Very Good
GAADL	40	100	Very Good
JFA	35	87.5	Very Good
KOF	35	87.5	Very Good
KPNA	35	87.5	Very Good
KAK	40	100	Very Good
KJAR	37	92.5	Very Good
MRFA	37	92.5	Very Good
MRHI	37	92.5	Very Good
MMA	36	90	Very Good
MNIA	40	100	Very Good
MZAR	37	92.5	Very Good
NKN	39	97.5	Very Good
NDR	37	92.5	Very Good
RFA	40	100	Very Good
RNA	40	100	Very Good
RPP	40	100	Very Good
SDL	40	100	Very Good
QNA	40	100	Very Good
ASPA	40	100	Very Good
Percentage of average student response results		95.58	Very Good

Students have completed the student response questionnaire, with 95.58% stating "very good." In addition, student comments were very positive, such as "The images are interesting," the audio explanation facilitates understanding of photosynthesis science material, as well as other positive comments that show student interest in the Augmented Reality (AR) Photosynthesis-based scansmart card media. Teachers also filled out a questionnaire regarding the Augmented Reality (AR) Photosynthesis Scansmart Card media, the results of which are presented in Table 9.

Table 9. Teachers responses to Augmented Reality (AR)-based Scansmart card media on photosynthesis

Teacher Name	Total Score	Percentage (%)	Category
BK	40	100	Very Good
Percentage of average teacher response results		100	Very Good

Table 9 shows that 100% of teachers' responses were categorized as "very good." Teachers were very satisfied with the development of this Augmented Reality (AR)-based scansmart card media. Teachers believe that this Augmented Reality (AR)-based scansmart card media helps students understand abstract scientific concepts more easily. This Augmented Reality (AR)-based scansmart card media is considered effective as a medium to support science learning. This Augmented Reality (AR)-based scansmart card media on photosynthesis for fourth-grade elementary school students brings revolutionary innovation to science education.

Evaluation

The evaluation phase was conducted based on input and suggestions from validators, media experts, subject matter experts, and users of the AR Photosynthesis Scansmart card media. This was done to ensure that the product was suitable for use in learning. Some of the input and suggestions from validators included minor revisions, such as larger font sizes for titles, paper thickness, and the addition of card designs with backgrounds that matched the plant theme. Therefore, prior to testing, the authors made revisions based on this feedback. The evaluation phase also assessed the effectiveness of the developed Scansmart Photosynthesis AR card media. Before testing the effectiveness of the media, which involved comparing pre-test and post-test scores, a normality test was required. The purpose of the normality test was to determine whether the collected data followed a normal distribution. The sample size in this study was 30, so the normality test used was the Shapiro-Wilk test (Indah &

Hadiana, 2024). Based on the decision criteria in the normality test, the data was considered to follow a normal distribution if the significance value (Sig) was greater than 0.05. Conversely, if the Sig value was less than 0.05, the data did not follow a normal distribution. The results are shown in Table 10.

Table 10. Normality test

Learning Outcomes	Statistics	Df	Sig (P-Value)
Pre-test	0.962	30	0.528
Post-test	0.971	30	0.642

Based on the results in the table, the normality test results show that the pre-test (Sig = 0.528) and post-test (Sig = 0.642) scores are greater than 0.05, indicating that both data sets are normally distributed. Therefore, a paired sample t-test was applied to analyze the difference between pre-test and post-test scores.

Table 11. Paired sample t-test

Variable	Mean of Pre-test	Mean of Post-test	t	Df	Sig (2-tailed)
Student Score	79.03	91.00	6.87	29	0.000

Based on the table, the paired sample t-test results indicate a significant difference between students' pre-test and post-test scores. The mean pre-test score was 79.03, while the mean post-test score increased to 91.00. The analysis showed a t-value of 6.87 with 29 degrees of freedom and a significance value of 0.000 ($p < 0.05$), indicating that the use of AR-based Scansmart Card media significantly improved students' understanding of photosynthesis concepts.

Table 12. Results of the N-gain data analysis for each student

Student Name	Pre-test	Post-test	N-gain	Category
ANZ	67	95	0.85	High
AGAS	85	95	0.67	Moderate
AAK	67	85	0.55	Moderate
ADZ	87	95	0.62	Moderate
AD	85	95	0.67	Moderate
AWD	90	100	1.00	High
DJP	77	85	0.35	Moderate
EAS	70	85	0.50	Moderate
EAG	92	100	1.00	High
FAA	70	75	0.17	Low
FEDA	74	85	0.42	Moderate
GAADL	86	95	0.64	Moderate
JFA	79	95	0.76	High
KOF	75	95	0.80	High
KPNA	89	100	1.00	High
KAK	86	95	0.64	Moderate
KJAR	70	80	0.33	Moderate
MRFA	75	85	0.40	Moderate
MRHI	76	85	0.38	Moderate
MMA	92	95	0.38	Moderate
MNIA	70	85	0.50	Moderate
MZAR	70	100	1.00	High
NKN	82	100	1.00	High
NDR	70	85	0.50	Moderate
RFA	70	85	0.50	Moderate
RNA	79	85	0.29	Low
RPP	80	85	0.25	Low
SDL	80	85	0.25	Low
QNA	93	100	1.00	High
ASPA	93	100	1.00	High

Based on Table 12, most students achieved N-gain values in the moderate and high categories. The average N-gain score was 0.63, which falls into the moderate category, indicating that the AR-based Scansmart Card learning media was effective in improving students' understanding of photosynthesis concepts.

Conclusion

This study concludes that the Augmented Reality (AR)-based Scansmart Card learning media is valid, feasible, and effective in improving fourth-grade students' understanding of photosynthesis concepts in IPAS learning. Expert validation results confirmed that the media is suitable for classroom implementation, and classroom trials showed very positive responses from both students and teachers. The effectiveness of the media was supported by a significant difference between pre-test and post-test scores based on the paired sample t-test ($t = 6.87$; $p < 0.05$) and an average N-gain score of 0.63 in the moderate category. These findings indicate that the AR-based Scansmart Card learning media enhances students' conceptual understanding and learning engagement in elementary science education.

Acknowledgments

The authors would like to thank Muhammadiyah University of Malang,particularly the Department of Elementary School Teacher Education,for its support, as well as the teachers and fourth-grade students of SDN Tlekung 02 Batu for their valuable participation.

Author Contributions

Conceptualization, Y.S.B. and A.R.; methodology, formal analysis, investigation, resources, research development and testing, Y.S.B.; validation of tools and initial product design validation before submission to media and material experts, supervisor who guided and directed the first author, A.R.

Funding

There was no external funding for this Research.

Conflicts of Interest

There is no Conflict of interest between the authors.

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