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Development of Mixed Reality Learning Media for the Solar System Based on Edu-Games to Increase Motivation and Retention of Elementary School Students

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Abstract

Background: The low science achievement of Indonesian students (PISA 2022) and elementary school solar system learning which is still verbal-2D causes motivation (average 46%) and low learning retention. This research aims to develop mixed reality solar system learning media based on edu-games that are valid, practical and effective to increase elementary school students' learning motivation and retention, in line with the STEAM approach and strengthening science-technology human resources (4th Asta Cita). **Methods:** The research method used the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model development design, which was implemented in elementary schools in Bangkalan Regency and Surabaya City. **Results:** The research on the development of mixed reality-based edu-game learning media for the solar system showed very positive results. The media was declared very valid based on validation by media experts (82%) and material experts (80.5%), very practical (87.5%), and very interesting (90.6%). The media was also effective in increasing learning motivation. In Surabaya, motivation increased from 68.75 to 78.38, while in Bangkalan from 53 to 61.2, with the results of the paired sample t-test $p = 0.000$ ($p < 0.05$). Student retention was also in the very good category, namely 100% in Surabaya and 83.6% in Bangkalan. **Conclusion:** The mixed reality-based edu-game learning media for the solar system was declared valid, practical, engaging, and effective. Media validation reached 82%, material 80.5%, practicality 87.5%, and student engagement 90.6%. The media was also shown to significantly increase learning motivation ($p < 0.05$) in both pilot schools. Student retention results were categorized as excellent, at 100% in Surabaya and 83.6% in Bangkalan. Thus, this media is suitable for use as an innovative alternative for elementary school science learning that supports the Merdeka Curriculum and STEAM-based learning.

INTRODUCTION

Science learning remains an important concern in Indonesia, particularly in developing students' ability to understand and apply scientific concepts. The PISA 2022 results indicate that only 34% of Indonesian 15-year-old students reached Level 2 or higher in science, compared with 76% across OECD countries. Thus, approximately 66% of Indonesian students performed below the baseline level of proficiency in science. At Level 2, students are expected to recognize appropriate explanations for familiar scientific phenomena and use basic scientific knowledge to determine whether a conclusion is supported by available data (Alifiyah et al., 2025; Bilad et al., 2024). Although PISA assesses students at age 15 rather than elementary school students, these findings provide an important national context for strengthening science learning from the earlier stages of education.

At the elementary school level, science learning also presents challenges when students are required to understand concepts that are abstract or difficult to observe directly, including the solar system (Darmayanti et al., 2025). Conventional explanations that rely primarily on verbal descriptions and two-dimensional representations may provide limited opportunities for students to visualize the relationships and movements of celestial objects (Nurlita et al., 2024). These limitations can influence students' engagement with science learning. Previous studies have reported relatively low levels of student learning motivation, including an average motivation score of approximately 46% in elementary learning contexts (Li, 2024; Orji & Vassileva, 2023; Siswanto et al., 2022). Retention is another important consideration because meaningful learning requires students to retain and recall knowledge and experiences after the learning activity has ended (Gupta, 2025). Students with stronger retention are more likely to recall previously learned information and use it in subsequent learning situations (Salame et al., 2024). Previous research has also indicated that student retention in Indonesia remains a concern (Raspatiningrum et al., 2025; Rahmat, 2025; Talar & Gozaly, 2020).

A preliminary needs analysis was conducted before the development of the learning media to identify the characteristics, learning needs, and difficulties of sixth-grade elementary school students in science learning in Bangkalan Regency and Surabaya City. The analysis focused particularly on the teaching and learning of solar-system concepts, as well as students' motivation and retention. Data were collected using observation, semi-structured interviews, documentation, and questionnaires involving teachers and students. The observations examined classroom learning activities and the use of instructional media, while the interviews explored teachers' experiences in teaching science, students' learning difficulties, and the challenges of presenting abstract solar-system concepts. Questionnaires were used to obtain additional information regarding students' learning characteristics and responses to science learning. The needs analysis indicated that learning activities required media that could provide more concrete visualization, interactive experiences, and opportunities for students to engage directly with the learning content. These findings provided the basis for developing an edu-game-based Mixed Reality medium that could integrate visualization, interaction, and game-based learning into the teaching of the solar system.

One factor that may contribute to these learning difficulties is the use of instructional strategies and media that are not sufficiently aligned with students' learning characteristics and the increasing role of digital technology in education (Zou et al., 2025;

Mansori et al., 2024). Technology-supported learning has received positive responses from students and educators because it can provide more varied opportunities for interaction with learning content (Meadati & Juneja, 2015). Students have also shown greater interest and positive engagement when technology is incorporated into learning activities (Alenezi et al., 2023). However, the educational value of technology depends not only on its presence in the classroom but also on how it is integrated with meaningful learning activities and the characteristics of the content being taught.

Edu-games represent one possible approach because they combine learning objectives with interactive and game-based experiences. Through edu-games, students can interact directly with digital content and receive learning experiences that are more engaging than passive exposure to information (Budiman et al., 2023; Ball et al., 2020). Interactive game-based environments can encourage students to participate actively in learning activities (Jantakun & Jantakoon, 2021), while play provides opportunities for students to explore, practice, and construct knowledge through experience (Pratiwi et al., 2024). For science topics that involve objects and processes that cannot be directly observed, interactive digital environments may therefore provide additional support for visualization and engagement.

Mixed reality (MR) offers a further opportunity to integrate these characteristics into science learning. MR combines real-world and digital elements and enables virtual objects to be presented within an interactive environment. Previous research involving augmented reality (AR) has reported potential benefits for learning outcomes, retention, and motivation (Nadhia et al., 2023; Yusa et al., 2023). Earlier research by the research team also explored virtual reality (VR) as a learning medium and found that its use was associated with improved student retention (Abdussalam et al., 2018). However, VR generally requires students to interact through a fully or partially immersive environment, which may restrict physical mobility and reduce direct awareness of the surrounding classroom environment. AR provides greater mobility and preserves interaction with the physical environment, although its visualization capabilities may be more limited than those of immersive VR. These characteristics suggest that integrating elements of AR and VR through MR may provide a more balanced learning experience by allowing students to interact with digital representations while remaining connected to the physical learning environment.

Previous research on MR has demonstrated its potential to support interactive learning by connecting digital objects with real-world contexts and providing opportunities for learners to manipulate and explore virtual representations. Such applications are particularly relevant to science learning because phenomena that are difficult to observe directly can be represented through interactive three-dimensional objects and simulations. Nevertheless, previous studies have generally examined MR in relation to learning interaction, conceptual understanding, or learning outcomes, while comparatively less attention has been given to the simultaneous development of learning motivation and retention through an MR-based edu-game for elementary science, particularly in the context of solar-system learning.

The novelty of the present study lies in the integration of MR and edu-game principles into a learning medium specifically designed to support elementary students in learning about the solar system while addressing two learning-related outcomes, namely motivation and retention. Rather than presenting MR solely as a visualization technology, the present study positions MR within a game-based learning experience in which students

can interact with digital representations of solar-system objects while remaining connected to the physical learning environment. This approach is intended to provide students with a more concrete and engaging learning experience for concepts that are otherwise difficult to visualize through conventional two-dimensional media. Based on this rationale, the present study addresses the need for learning media that can connect technological interaction, visualization, and game-based learning with the specific learning characteristics of elementary science. The study therefore aimed to develop and examine an MR-based edu-game for solar-system learning and to determine its potential to support students' learning motivation and retention. The study was guided by the assumption that integrating interactive MR experiences with game-based activities may provide students with more meaningful opportunities to engage with and recall abstract science concepts.

METHODS

This study used a research and development approach based on the ADDIE model, which consists of five stages: analysis, design, development, implementation, and evaluation (Branch, 2009). The model was used to provide a systematic process for identifying learning needs, designing and developing the learning media, conducting product trials, and evaluating the developed product. Following the development process, a one-group pretest–posttest design was used to examine changes in students' learning motivation and retention after using the edu-game-based Mixed Reality solar-system learning media. The participants were sixth-grade elementary school students from SDN Tanah Kalikedinding 1 Surabaya and SDN Kraton 2 Bangkalan.

The analysis stage was conducted to identify student characteristics, learning needs, learning conditions, and difficulties in teaching solar-system concepts (Sukmawati, 2025; Hidayat, 2024). Qualitative and quantitative information was collected through observation, interviews, documentation, and questionnaires (Abdussalam et al., 2025). Classroom observations focused on learning activities, student participation, learning media, and difficulties in presenting abstract solar-system concepts. Interviews with teachers were conducted to obtain information about students' learning characteristics, motivation, retention, and learning difficulties. The information obtained during this stage was used as a basis for determining the learning content, activities, visual representations, and game features to be incorporated into the media.

The design stage was based on the findings of the analysis stage and the learning objectives of elementary science education. At this stage, the solar-system content, learning sequence, game activities, Mixed Reality features, interface, and assessment components were planned. Four instruments were prepared: a learning motivation questionnaire, a retention test, an expert validation sheet, and a student practicality questionnaire. The motivation questionnaire was used to assess students' motivation before and after using the media. The retention test was prepared according to the learning objectives and solar-system material presented in the media. The expert validation sheet was used to assess the quality and suitability of the developed media, while the practicality questionnaire was used to obtain students' responses to the media.

The instruments were developed by identifying the indicators to be measured, preparing items according to the indicators, adjusting the language to the characteristics of sixth-grade students, and aligning the assessment items with the learning objectives. The development stage involved preparing digital learning resources and developing the

edu-game-based Mixed Reality solar-system application. The application was designed for use with a Meta Quest headset and included an astronaut username feature, a rocket-launch menu, educational content, and game-based exercises.

The learning content presented three-dimensional representations of the Sun and planets in a Mixed Reality environment. Students could explore the objects using the Meta Quest controllers and access information through narration and written text. The practice section consisted of multiple-choice questions and an educational game in which students interacted with virtual aliens. A user manual was also developed to provide instructions for operating the application.

The developed media was then assessed by media and subject matter experts. The media validation consisted of 21 aspects covering instructions, learning objectives, support for remembering learning material, attention, learning environment, ease of use, text, animation, sound, typography, color, images, background, student characteristics, layout, language, safety, program organization, and overall quality. The subject matter validation consisted of five aspects covering content accuracy, depth of material, clarity, ease of understanding, and practice questions. Expert comments and suggestions were used to revise the media before the student trial.

An individual/small-group trial was conducted with three sixth-grade students at SDN Tanah Kalikedinding 1 Surabaya. The students represented high, medium, and low levels of ability. The trial was conducted to examine the attractiveness and practicality of the developed media before its implementation in the field trial. Student responses were collected through a questionnaire and supplemented by student comments concerning image and text clarity, graphics, audio volume, comfort when using the Mixed Reality device, and the learning experience. The results were used to make further revisions to the media.

The revised media was implemented in sixth-grade classes at SDN Tanah Kalikedinding 1 Surabaya and SDN Kraton 2 Bangkalan. Before using the media, students completed the learning motivation questionnaire and retention assessment. Students then participated in science learning activities using the edu-game-based Mixed Reality solar-system media with the Meta Quest headset. After the learning activities, the motivation questionnaire and retention assessment were administered again. Data analysis focused on the validity, attractiveness, practicality, and changes in students' motivation and retention. The validity of the media was determined from expert assessment. The media validation consisted of 21 aspects, while the subject matter validation consisted of five aspects. The percentage score was calculated by comparing the obtained score with the maximum possible score:

$$\textbf{Percentage} = (\textbf{Obtained score} / \textbf{Maximum possible score}) \times 100\%$$

The resulting percentage was interpreted according to the criteria in (Akbar, 2013). A percentage above 60.01% met the minimum validity criterion. Attractiveness and practicality were determined from student responses during the individual/small-group trial. The percentage scores were calculated using the same procedure and interpreted according to the criteria in (Akbar, 2013). Changes in learning motivation were analyzed using a paired-samples t-test to compare pretest and posttest scores. The significance level was set at $\alpha = .05$. The results were interpreted as changes observed between the pretest and posttest following the use of the developed media.

RESULT AND DISCUSSION

The development research resulted in a specific product is an educational game-based mixed reality learning medium focused on the solar system, delivered as an application designed for installation and use on the Meta Quest headset. The application presents solar system content aligned with the learning competency of explaining the solar system and the characteristics of its constituent bodies. Its compatibility is limited to supported Meta Quest devices and does not extend to all operating systems. The medium is designed to improve students' understanding, retention, and motivation to learn about the solar system.

The content focuses on the Sun and the planets, presented via mixed reality to create an immersive experience where users feel as though they are directly viewing these celestial bodies in space. Users view these objects with the aid of the Meta Quest headset. Additionally, the medium assists educators in teaching solar system concepts a topic often considered challenging due to the difficulty of showing students tangible examples of the objects involved.

The application features several user-selectable menus: a name entry field for the "astronaut," a rocket ship option (to begin exploring the solar system), and buttons for educational content and practice exercises. Selecting the rocket ship initiates the mixed reality experience, featuring 3D models of the Sun and planets accompanied by narration and informational text for each object. Another menu offers practice exercises, consisting of multiple-choice questions combined with an alien-elimination game where players target aliens approaching them. The following section provides a detailed discussion of this developed educational game-based mixed reality medium. The learning media developed is presented in the form of an application. In the main display of the application there are several menus consisting of entering a username, keyboard, rocket launcher and virtual garden space. The form of the main display or media opener can be seen in Figure 1



Figure 1. Initial display of the Solar System mixed reality medium

This learning tool utilizes the Meta Quest headset. Once the developed application is installed on the device, users can experience a virtual world featuring the Sun and various planets. To examine the objects more closely, users operate the controllers to navigate toward them and access information provided by a narrator and accompanying text for each object. In the second display, the user has reached outer space with the appearance of flying as an astronaut. At this point the user can see the surroundings consisting of stars. There are two menus in front of the user, namely the solar system

material menu and the questions menu in the form of educational games. The appearance can be seen in the following image.



Figure 2. Space view and menu

In this view there are sun and planetary objects. The first thing you will see is an explanation of what the solar system is. Then the user can use the console to circle the solar system which contains the sun and planets. The appearance can be seen in the following image.



Figure 3. Material Display

In this display the user will complete the mission by answering questions while being on guard against aliens appearing to attack the user. If there are aliens, the user can eliminate them by shooting the aliens. While working on questions, users also remain alert if at any time aliens appear. The appearance can be seen in the following image.

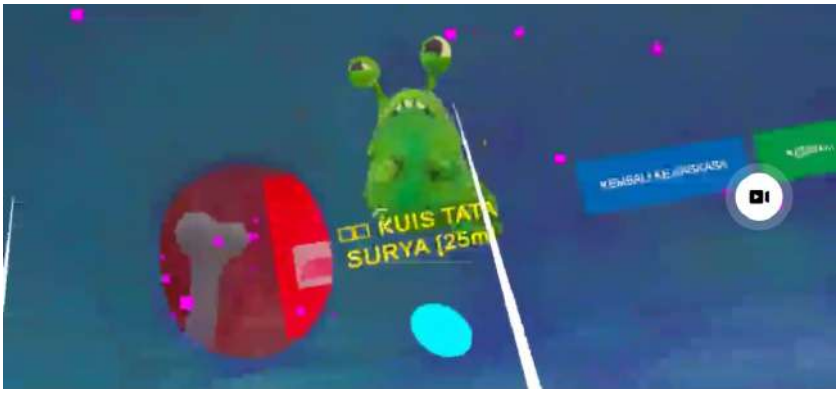


Figure 4. Edu-Game interface

The question aims to assess the students' understanding of the concepts taught. It also serves to evaluate the effectiveness of the media in conveying the material and to determine whether the students have successfully grasped the content. The question is displayed in the image below.



Figure 5. Question Display

The use of this media cannot be separated from the instructions for using it. Instructions for using the media are created and presented by the developer to make it easier for users to use the media. Instructions for using the media are presented in book form with A5 paper size and use Times New Roman font. The media usage manual contains a book cover, foreword, table of contents, introduction, media description, etc. The following is a display of the edu-game based solar system mixed reality media manual which can be seen in figure 6.



Figure 6. Cover of the Media Use Instructions Book

When learning activities using this media, it is best to first read the user manual or usage guide to avoid errors in use and optimize the use of the media in each learning activity. This user manual can be used by educators and students. The contents of this book are guidelines that can be used during learning activities using media and there are maintenance and maintenance guidelines so that this media can be used for a longer period of time. The use of mixed reality solar system learning media based on edu-games cannot be separated from the use of meta quest tools. This meta quest helps to maximize the application of media so that it becomes an inseparable unit. The following is the appearance of the meta quest tool which can be seen in Figure 7.



Figure 7. Meta Quest device

When using media in the learning process, meta quest tools are an important part of media application to be able to see objects and move around in the virtual world of the solar system. The meta quest tool helps to run virtual programs of solar system material. The learning media developed has been completed, then validation activities are carried out so that the media can be declared valid for use during the learning process. The results of the validation process or activities will later obtain data in the form of quantitative data and qualitative data. Quantitative data is obtained from the scoring results by each expert. Meanwhile, qualitative data was obtained from criticism, suggestions and input from each expert.

This media validation is carried out by media and material experts. Media experts are lecturers who have expertise in the field of learning media with a minimum qualification for a Doctoral program (S3), while material experts are lecturers who have expertise in the field of solar system materials in accordance with the material in the media with a minimum qualification for a Doctoral program (S3). However, in the validation process there are several criticisms, suggestions and input from experts or experts so that the learning media developed can be even better. Below are the validation results from several experts. Media expert validation of the media consists of 21 aspects. The following are the results of validation by media experts.

Table 1. Media Expert Validation Results

Validation Aspect	Validation Score	∑x	Percentage	Interpretation
Clarity of the user instructions	3	4	75%	Valid
Alignment of the media with the learning objectives	3	4	75%	Valid
Suitability of the media as an aid for recalling learning materials	3	4	75%	Valid
Ability of the media to attract students' attention	4	4	100%	Highly Valid
Suitability of the media for the learning environment	4	4	100%	Highly Valid
Ease of using the media	3	4	75%	Valid
Clarity of the text	3	4	75%	Valid
Clarity of the animations	3	4	75%	Valid
Clarity of the audio	4	4	100%	Highly Valid
Appropriateness of the font type	3	4	75%	Valid
Appropriateness of the font size	3	4	75%	Valid
Appropriateness of the color selection	4	4	100%	Highly Valid
Attractiveness of the color combination	3	4	75%	Valid
Clarity of the images used	3	4	75%	Valid
Appropriateness of the background design	3	4	75%	Valid
Suitability of the program interface for students' characteristics	4	4	100%	Highly Valid
Attractiveness of the media layout	4	4	100%	Highly Valid
Accessibility and comprehensibility of the language	3	4	75%	Valid
Safety of the media for users	3	4	75%	Valid
Systematic presentation of the overall program	3	4	75%	Valid
Overall media quality	3	4	75%	Valid
Average			82%	Highly Valid

Based on the percentage of validation results carried out by learning media experts on the media developed, the percentage score was 82%. The percentage results from the validation of learning media experts can be concluded that the media developed can be used because the percentage results obtained a score exceeding the minimum score, namely 60.01% (Akbar, 2013). Criticism, suggestions and input provided by learning media experts regarding the media as well as revisions made can be seen in table 2.

Table 2. Before and After Revision (Media Expert)

Before Revision	After Revision
The narrator's voice quality and the level of detail in the explanation needed improvement.	The narration was re-recorded to improve voice clarity. The explanations were also expanded by adding a dedicated learning materials menu to provide more detailed information.
The media was considered insufficiently interactive.	The learning media has limited interactivity because it was not originally designed as an interactive medium. Nevertheless, the developer enhanced its communicative features by incorporating narration to make the learning experience more engaging and accessible.
Additional text was needed to support the explanation.	Additional text was incorporated to provide clearer explanations and facilitate students' understanding of the concepts presented.

The subject matter expert validation of the media covers five aspects. The results of the validation by the subject matter expert are presented in Table 3.

Table 3. Subject Matter Expert Validation Results

Evaluation Aspect	Average Score (%)	Interpretation
Accuracy of the learning content	100%	Highly Valid
Depth of the content in accordance with elementary school students' characteristics	75%	Valid
Clarity of the learning content	77.50%	Valid
Ease of understanding the learning content	75%	Valid
Quality and appropriateness of the practice questions	75%	Valid
Average Score	80.50%	Highly Valid

Based on the percentage of validation results carried out by learning material experts on the media developed, the percentage score was 80.5%. The percentage results from the validation of learning material experts can be concluded that the media developed can be used because the percentage results obtained a score exceeding the minimum score, namely 60.01% (Akbar, 2013). Criticism, suggestions and input provided by learning material experts regarding the media as well as revisions made can be seen in table 4.

Table 4. Before and After Revision (Subject Matter Expert)

Before Revision	After Revision
There was no pause button available in the Mixed Reality application.	A pause button has been added to the Mixed Reality application.
There was no exit button for leaving the Mixed Reality environment.	An exit button has been added to allow users to leave the Mixed Reality environment.
A miniature solar system should be displayed in front of the astronaut.	A miniature solar system has been added in front of the astronaut during the explanation of the solar system.
Interactive narration should be added for each object.	Interactive narration has been incorporated for each object to enhance user engagement during learning.
The word "Skip" in each text should be replaced with "Continue the Journey."	The word "Skip" has been replaced with "Continue the Journey." throughout the application.

Before Revision	After Revision
In the practice exercises, the scoring system should be changed to a 0–100 scale.	The scoring system in the practice exercises has been revised to use a 0–100 scale.

The next stage after the expert validation stage is testing the learning media products being developed. The product trial stage can be carried out if the product being developed is declared valid for use through an expert validation process. Product trials were carried out on sixth grade elementary school students, at SDN Tanah Kalikedinding 1 Surabaya and SDN Kraton 2 Bangkalan. This learning media product trial was carried out in 2 stages, namely individual trials (small groups) and large group trials. The purpose of the trial was to determine students' responses to learning media in terms of media attractiveness and media practicality. Meanwhile, to see the level of effectiveness of media products, a product effectiveness test was carried out at the large group trial stage. Below are the results of testing learning media products.

The first stage in testing the learning media products being developed is the individual (small group) trial stage. Individual trials were carried out on three class VI students at SDN Tanah Kalikedingding 1 Surabaya. Three students represent the ability levels in the class, namely high, medium and low ability. The aim of carrying out this trial is to see the level of attractiveness and practicality of the media being developed. Following are the percentages of individual trial results that have been analyzed, which can be seen in table 5.

Table 5. Student Response Results

Evaluation Aspect	Average Score (%)	Interpretation
Attractiveness of the VRTS learning media	90.60%	Highly Valid
Practicality of the VRTS learning media	87.50%	Highly Valid

Based on the analysis of student responses during the individual (small-group) trial regarding the appeal and practicality of the developed learning media, it can be concluded that the media is both appealing and practical. The media achieved an appeal rating of 90.6%, exceeding the 61% threshold required to be considered appealing (Akbar, 2013). Meanwhile, the media achieved a practicality rating of 87.5%, also exceeding the 61% threshold required to be considered practical (Akbar, 2013). Criticisms, suggestions, and feedback provided by students regarding the media during the individual (small-group) trial phase are presented in Table 6.

Table 6. Before and After Revision (Student Responses)

Before Revision	After Revision
The clarity of the images and text needs to be improved.	The images and text are sufficiently clear. Any perceived lack of clarity may be related to users not adjusting the lenses of the Meta Quest device properly.
The graphics and audio volume need to be improved.	The graphic quality has reached the maximum level supported by the development process and therefore cannot be further enhanced. The audio volume can be increased through the smartphone settings.

The Mixed Reality experience was interesting but caused some discomfort or dizziness.	The discomfort may have resulted from improper lens adjustment. When the lenses are adjusted correctly, the experience should be more comfortable.
The Mixed Reality media provides learning benefits.	-
The Mixed Reality media was enjoyable because it helped users become familiar with solar system concepts.	-

Following expert validation and the individual/small-group trial, the developed media was implemented in two Grade VI classes: SDN Kraton 2 Bangkalan and SDN Tanah Kalikedinding 1 Surabaya. The two schools were selected because they shared several school-level characteristics, including an "A" accreditation rating and Grade VI teachers with bachelor's-level qualifications (Strata 1), while representing different geographical and school-community contexts. SDN Kraton 2 represents a regency setting in Bangkalan, whereas SDN Tanah Kalikedinding 1 represents an urban setting in Surabaya. These similarities provided a comparable educational context for implementation, while the different settings allowed the media to be examined across two distinct school environments.

Table 7. Results of Student Motivation: Grade VI, SDN Tanah Kalikedinding 1 Surabaya

No.	Pretest Motivation Questionnaire	Category	Post-test Motivation Questionnaire	Category
1.	67	High	77	High
2.	47	Moderate	62	High
3.	37	Low	50	Moderate
4.	60	Moderate	75	High
5.	92	Very High	97	Very High
6.	55	Moderate	72	High
7.	92	Very High	97	Very High
8.	90	Very High	95	Very High
9.	100	Very High	100	Very High
10.	82	Very High	87	Very High
11.	82	Very High	90	Very High
12.	60	Moderate	75	High
13.	57	Moderate	70	High
14.	37	Low	50	Moderate
15.	65	High	70	High
16.	77	High	87	Very High
17.	57	Moderate	70	High
18.	37	Low	50	Moderate
19.	65	High	70	High
20.	77	High	87	Very High
TOTAL	1.100		1.254	
MEAN	68.75		78.38	

Based on the table above, during the pretest the learning motivation questionnaire obtained an average of 68.75 and during the posttest the learning motivation questionnaire obtained an average score of 78.38, which overall saw an increase in student learning motivation from pretest to posttest.

Table 8. Paired-Sample T-Test Results for the Student Motivation Questionnaire (Grade VI, SDN Tanah Kalikedinding 1 Surabaya)

Paired Samples Test								
		Paired Differences					T	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pretest Motivation – Posttest Motivation	-8.125	4.801	1.200	-10.683	-5.567	-6.769	15.000	

Based on the output above, the sig. (2-tailed) value is 0.000 (< 0.05); therefore, it can be concluded that there is a difference in the mean learning motivation of Grade VI students at SDN Tanah Kalikedinding 1 Surabaya when using the Solar System Mixed Reality Learning Media (based on an educational game), indicating an increase in their learning motivation.

Table 9. Results of Student Motivation: Grade VI, SDN Kraton 2 Bangkalan

No.	Pretest Motivation Questionnaire	Category	Post-test Motivation Questionnaire	Category
1.	82	Very High	90	**Very High**
2.	60	Moderate	75	**High**
3.	57	Moderate	70	**High**
4.	37	Low	50	**Moderate**
5.	65	High	70	**High**
6.	77	High	87	**Very High**
7.	57	Moderate	70	**High**
8.	37	Low	50	**Moderate**
9.	65	High	70	**High**
10.	77	High	87	**Very High**
11.	67	High	77	**High**
12.	47	Moderate	62	**High**
13.	37	Low	50	**Moderate**
14.	60	Moderate	75	**High**
15.	92	Very High	97	**Very High**
16.	55	Moderate	72	**High**
17.	92	Very High	97	**Very High**
18.	90	Very High	95	**Very High**
19.	60	Moderate	70	**High**
20.	82	Very High	87	**Very High**
TOTAL	1.060		1.224	
MEAN	**53**		**61.2**	

Based on the table above, during the pretest the learning motivation questionnaire obtained an average of 68.75 and during the posttest the learning motivation questionnaire obtained an average score of 78.38, which overall saw an increase in student learning motivation from pretest to posttest.

Table 10. Paired Sample T-Test Motivation Questionnaire for Class VI Students of SDN Kraton 2 Bangkalan

Paired Samples Test								
		Paired Differences					T	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pretest Motivation – Posttest Motivation	-8.525	4.441	1.100	-9.683	-5.467	-6.469	15.000	

Based on the output above, a sig (2-tailed) value of 0.000 < 0.05 is obtained, so it can be concluded that students' learning motivation shows an average difference using Edu-Game Based Solar System Mixed Reality Learning Media so that there is an increase in learning motivation for Class VI students at SDN Kraton 2 Bangkalan. Student retention was assessed during the field implementation to examine students' ability to recall the solar-system material after participating in learning activities using the developed Mixed Reality media. The assessment was administered under the same learning procedures at SDN Tanah Kalikedinding 1 Surabaya and SDN Kraton 2 Bangkalan. Students' retention may be related to both internal conditions, such as individual differences in attention and ability to recall information, and external conditions, including the learning environment, instructional activities, and use of the learning media. The retention results for the two schools are presented in Table 11.

Table 11. Retention results for class VI students at SDN Tanah Kalikedinding 1 Surabaya

Attendance No.	Number of Questions Understood		Percentage	Interpretation
	Pretest Retention	Post-test Retention		
1	14	14	100	Very Good
2	17	17	100	Very Good
3	18	18	100	Very Good
4	17	17	100	Very Good
5	14	14	100	Very Good
6	17	17	100	Very Good
7	16	16	100	Very Good
8	16	16	100	Very Good
9	14	14	100	Very Good
10	18	18	100	Very Good
11	17	17	100	Very Good
12	15	15	100	Very Good
13	14	14	100	Very Good
14	15	15	100	Very Good
15	19	19	100	Very Good
16	15	15	100	Very Good
17	17	17	100	Very Good
18	13	13	100	Very Good
19	11	11	100	Very Good
20	14	14	100	Very Good
Average			100	Very Good

Table 12. Retention results of Grade VI students at SDN Kraton 2 Bangkalan

Attendance No.	Number of Questions Understood		Percentage	Interpretation
	Pretest Retention	Post-test Retention		
1	15	12	80	Very Good
2	14	10	71.4	Good
3	15	13	86.6	Very Good
4	17	14	82.3	Very Good
5	15	12	80	Very Good
6	17	14	82.3	Very Good
7	15	13	93.3	Very Good
8	16	15	93.7	Very Good
9	16	11	68.7	Fair
10	10	10	100	Very Good
11	16	14	87.5	Very Good
12	12	11	91.6	Very Good
13	14	12	85.7	Very Good
14	19	17	89.4	Very Good
15	14	11	78.5	Good
16	13	10	76.9	Good
17	14	13	92.8	Very Good
18	16	13	81.2	Very Good
19	17	14	82.3	Very Good
20	13	9	69.2	Good
Average			83.6	Very Good

Table 13. Comparison of Retention Results of Grade VI Students at SDN Tanah Kalikedinding 1 Surabaya and SDN Kraton 2 Bangkalan

Class	Average Score	Interpretation
Grade VI, SDN Tanah Kalikedinding 1, Surabaya	100%	Very Good
Grade VI, SDN Kraton 2	83.60%	Very Good

Based on the student retention results at SDN Tanah Kalikedinding 1 Surabaya and SDN Kraton 2 Bangkalan using the developed media, it can be concluded that the Grade VI class at SDN Tanah Kalikedinding 1 Surabaya achieved a score of 100% (classified as "Very Good"), while the Grade VI class at SDN Kraton 2 Bangkalan achieved 83.6% (also classified as "Very Good").

Research on the development of this edu-game-based mixed reality learning medium for the solar system has yielded highly positive results regarding validity, practicality, appeal, and effectiveness (Sari et al., 2025; Anugrah et al., 2022). Media expert validation resulted in an average score of 82% (categorized as "highly valid"), while subject matter expert validation yielded an average score of 80.5% (also "highly valid"). These results confirm that the developed medium meets feasibility standards in terms of both visual presentation and content. Key highlights from the media expert validation included the medium's ability to capture students' attention and the alignment of the program's visual design with student characteristics; both aspects achieved a score of 100%. Meanwhile, subject matter expert validation confirmed 100% accuracy in the content, ensuring alignment with elementary school science basic competencies. These findings align with research, which indicates that interactive edu-game-based media can improve

elementary students' science learning outcomes by presenting material in a more contextual and engaging manner (Eliyanti et al., 2025). The practicality of the media also proved to be high. Small-group trials yielded a practicality score of 87.5%, placing it in the "highly practical" category. Students found the media easy to use, although there was feedback regarding the clarity of images and graphs, as well as the adjustment of the Meta Quest headset. Revisions such as the addition of pause and exit buttons and interactive narration for each object further enhanced the media's practicality. This demonstrates that immersive technology-based media can be effectively adapted for the primary school learning context. Research confirms that spatial immersive learning environments in primary education can boost student engagement, provided the media is designed with ease of use and accessibility in mind (Daghriri et al., 2024).

The media's appeal was another standout feature. Student responses during individual trials resulted in an appeal score of 90.6%, categorizing it as highly valid. Students were captivated by the immersive learning experience, which allowed them to explore the solar system firsthand through mixed reality. This aligns with learning motivation theories stating that emotional engagement and hands-on experiences can enhance students' intrinsic motivation. In their systematic review, emphasize that gamification and educational games play a crucial role in supporting the cognitive development and motivation of primary school students, particularly when combined with the teacher's role as a facilitator (Daghriri et al., 2024).

The effectiveness of the media in enhancing student motivation and retention was demonstrated through large-group trials. At SDN Tanah Kalikedinding 1 Surabaya, the average student motivation score rose from 68.75 in the pretest to 78.38 in the posttest. Meanwhile, at SDN Kraton 2 Bangkalan, motivation increased from 53 to 61.2. Paired-sample t-test results yielded a significance value (2-tailed) of 0.000 ($p < 0.05$), indicating a statistically significant increase in motivation. Student retention also improved significantly; retention reached 100% (categorized as "very good") in Surabaya and 83.6% (also "very good") in Bangkalan. These results demonstrate that the media not only boosts learning motivation but also helps students retain their understanding of concepts over a longer period. These findings align with research, which confirms that interactive educational games enhance the retention of science concepts by actively engaging students in the learning process.

CONCLUSION

Based on the research findings and discussion, it can be concluded that the developed edu-game-based mixed reality learning medium for the solar system is valid, practical, engaging, and effective. Media expert validation yielded an average score of 82% (categorized as highly valid), while subject matter expert validation yielded an average score of 80.5% (also highly valid). The medium was deemed practical, with a student practicality score of 87.5%, and engaging, with a student engagement score of 90.6%. It proved effective in enhancing student motivation and retention; learning motivation increased significantly ($p < 0.05$) at both trial schools, while student retention reached the "very good" category (100% in Surabaya and 83.6% in Bangkalan). Thus, this learning medium is suitable for use as an innovative alternative for science education in elementary schools, supporting the Merdeka Curriculum and STEAM-based learning.

DECLARATION OF GENERATIVE AI

The authors declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

CONFLICTING INTEREST STATEMENT

The authors declare that they have no known financial interests or personal relationships with any individuals or organizations that could influence or potentially introduce bias into the research reported in this article.

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