SPEKTA
(Jurnal Pengabdian Kepada Masyarakat: Teknologi dan Aplikasi)
ISSN 2723-8016 (online) | 2723-8008 (print)
Vol 7, No. 1, pp. 239-256

Mixed Reality–Based Solar System Learning Media for Enhancing Technological Literacy and Student Interaction in Elementary Education

Galih Ashari R[1*], Eka Noviana[2], Sri Retnoningsih[2], Maulana Seno Aji[1], Muhammad Figo Razzan[1], Dhimas Aji[1], Muhammad Alif Syaikhan[2], Raka Gaizka A[2], Ariq Zaki Muhamad[2]
[1]Department of Informatics, Institut Teknologi Nasional Bandung, Indonesia
[2]Department of Visual Communication Design, Institut Teknologi Nasional Bandung, Indonesia
*Corresponding Author: galihas@itenas.ac.id

ARTICLE INFO

Article history
Received January 30, 2026
Revised April 15, 2026
Accepted May 21, 2026

Keywords
Community service;
Mixed reality;
Solar system;
Student interaction;
Technology literacy.

ABSTRACT

Background: The rapid advancement of digital technology has encouraged the development of learning approaches that support not only knowledge acquisition but also collaboration and interaction.
Contribution: This study proposes a Mixed Reality (MR)-based solar system learning media with multiplayer features to enhance technological literacy and student interaction in elementary education.
Methods: An evaluative mixed-method approach was employed involving 37 students and 8 teachers at SDIT Daarul Jihad. Data were collected through questionnaires, observations, and interviews, and analyzed using descriptive statistics and qualitative interpretation.
Results: The findings show that the MR-based learning media was positively perceived by both teachers and students. More than 88% of teachers reported improved student understanding and engagement, while over 90% of students experienced increased motivation and ease of use. In addition, 76.9% of students demonstrated high to very high confidence in explaining solar system concepts. The multiplayer feature also supported collaborative interaction and active discussion during learning activities.
Conclusions: The MR-based collaborative learning media demonstrates strong potential in enhancing both cognitive and social aspects of learning in elementary education and provides practical insights into the integration of immersive collaborative learning technologies in classroom settings.

1. Introduction

The rapid advancement of digital technology has significantly influenced educational practices, particularly in supporting student-centered learning models [1]. In the 21st century, effective education demands not only the transmission of knowledge but also the development of essential skills such as collaboration, communication, creativity, and critical thinking [2]. Within this context, educational media are expected to provide not only engaging visualizations but also opportunities for interactive and collaborative learning experiences. This demand is particularly relevant in science education, where abstract topics such as the solar system remain challenging for elementary school students when delivered through conventional instructional approaches [3]. Previous studies have shown that students often struggle to understand planetary motion, spatial relationships, and scale due to the limitations of traditional media [4]. To address these challenges, immersive technologies such as Augmented Reality (AR) and Virtual Reality (VR) have been widely explored in educational settings [4]. AR has been shown to enhance visualization by integrating virtual objects into real-world environments, thereby supporting students' conceptual understanding [5].

However, AR-based learning is often limited in terms of immersion and does not fully support real-time interaction among learners. On the other hand, VR provides a fully immersive experience but tends to isolate users into individual environments and may introduce accessibility issues, including device limitations and user discomfort such as motion sickness [6], [7]. These limitations indicate that while AR and VR offer valuable contributions, they are not yet optimal in supporting collaborative and socially interactive learning processes. Mixed Reality (MR), which integrates physical and digital environments into a unified interactive space, has emerged as a promising alternative to overcome these limitations. MR enables users not only to visualize three-dimensional objects but also to interact with them collaboratively in real time [8]. Previous studies have highlighted the potential of MR in enhancing learning experiences and user engagement [8], [9]. However, most existing MR implementations in education primarily focus on visualization and individual interaction, with limited emphasis on structured collaborative learning, particularly in elementary school contexts. Furthermore, empirical studies that specifically investigate the role of MR-based collaborative interaction in improving both cognitive and social learning outcomes at the primary education level remain limited, particularly in collaborative immersive learning contexts [10]–[12].

To systematically examine the contextual challenges in implementing immersive learning in elementary education, a root-cause analysis was conducted using a fishbone diagram [13]. This analysis categorizes key influencing factors into management, technological, pedagogical, and student-related aspects, as shown in Figure 1. The diagram illustrates that although immersive technologies have been introduced in classroom settings, significant limitations remain in facilitating meaningful interaction, collaborative engagement, and integration with instructional practices. These findings highlight a gap between technological capability and pedagogical implementation, particularly in enabling collaborative learning experiences.

 https://doi.org/10.12928/spekta.v7i1.15745

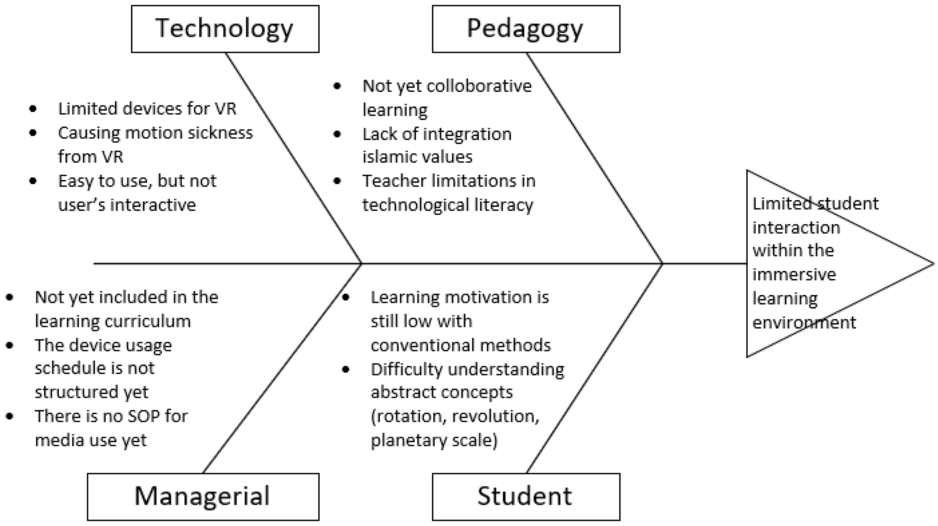

Figure 1. Fishbone Diagram for Problem Analysis

The analysis indicates that although immersive technologies have been introduced in classroom settings, limitations remain in facilitating meaningful interaction, collaborative engagement, and integration with instructional practices. These findings highlight a gap between technological capability and pedagogical implementation, particularly in enabling collaborative learning experiences. In a real classroom context, previous immersive learning implementations at SDIT Daarul Jihad demonstrated that while XR-based media improved visualization, they did not yet effectively support student interaction and collaborative learning. Teachers emphasized the need for features that enable group discussion, shared exploration, and active engagement. This condition reflects both a practical and empirical gap, where immersive technologies are present but not fully utilized to support collaborative learning processes. Based on these identified gaps, this study aims to investigate how a Mixed Reality–based solar system learning medium with multiplayer features can support collaborative learning and enhance technological literacy among elementary school students. Specifically, this study addresses the following research questions: First, how does the implementation of MR-based learning media with multiplayer features influence students' motivation, conceptual understanding, and interaction? Second, how do teachers perceive the usability and pedagogical relevance of MR-based collaborative learning media?

The novelty of this study lies in the integration of Mixed Reality technology with multiplayer collaborative features within a real elementary school context, supported by a participatory approach involving both teachers and students. Unlike previous studies that emphasize visualization through AR or immersion through VR, this study positions MR as a medium for collaborative interaction, aiming to bridge cognitive and social aspects of learning simultaneously. In addition, this study contributes to the development of an empirical model of collaborative immersive learning that is contextually grounded in real educational implementation.

2. Method

This section describes the research methodology employed in this study, including the research design, procedures, data collection methods, and analysis techniques used to evaluate the effectiveness of the Mixed Reality (MR)-based learning media. The methodological framework is designed to systematically examine both the implementation process and its impact on student interaction and technological literacy in an elementary school context.

2.1. Research Design

This study employed an evaluative research design using a mixed-method approach to assess the effectiveness of a Mixed Reality (MR)-based learning medium in enhancing student interaction and technological literacy in elementary education. The evaluative design was selected to examine both the implementation process and its educational outcomes within a real classroom context. By integrating quantitative and qualitative data, this approach enables a comprehensive analysis of both cognitive and social learning aspects. The overall research design is illustrated in Figure 2, which presents the sequential stages of the study, including needs assessment, design and development, implementation, evaluation, data analysis, and outcome identification. The process began with a needs assessment conducted through Focus Group Discussions (FGD) to identify learning challenges and user requirements. This was followed by the design and development phase, where the MR-based learning media with multiplayer features was developed and aligned with the curriculum context.

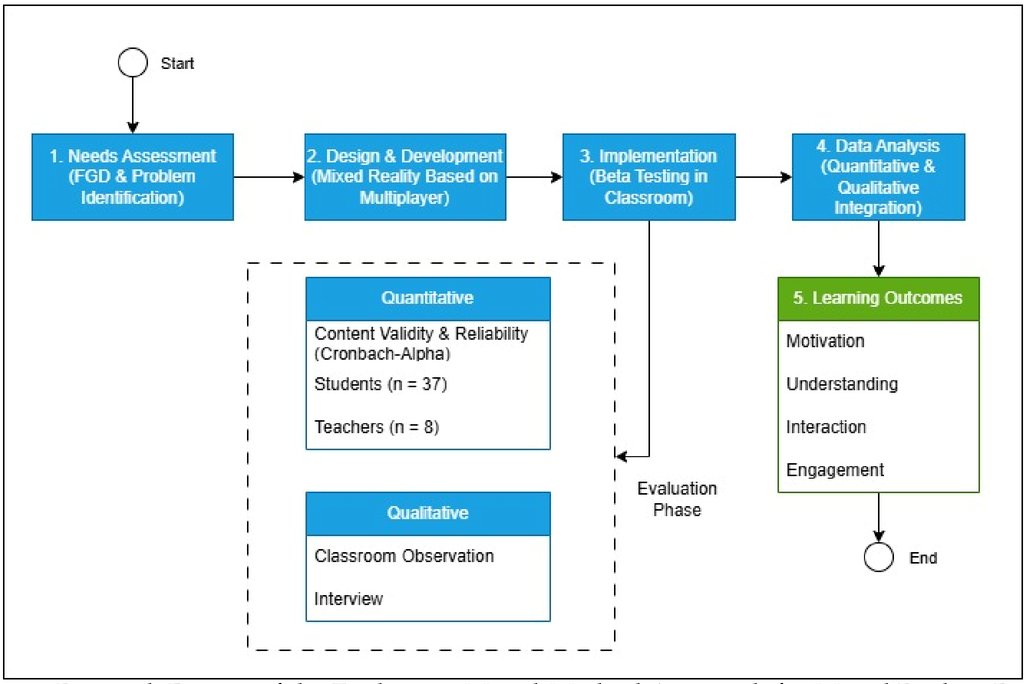

Figure 2. Research Design of the Evaluative Mixed-Method Approach for Mixed Reality–Based Learning Implementation

The implementation stage involved beta testing of the developed system in a classroom setting with active participation from students and teachers. Subsequently, the evaluation phase was conducted using a mixed-method approach. Quantitative data were collected

 https://doi.org/10.12928/spekta.v7i1.15745

through structured questionnaires that had undergone content validity and reliability assessment, involving 37 students and 8 teachers after a data cleaning process to remove duplicate and invalid responses. Qualitative data were obtained through classroom observation and interviews to capture student engagement, interaction, and collaborative behavior during the learning process. As shown in Figure 2, the collected data were analyzed through descriptive statistical analysis and qualitative interpretation, followed by methodological triangulation to ensure the consistency and validity of findings. This integrated analysis enables a comprehensive evaluation of learning outcomes, including motivation, conceptual understanding, interaction, and engagement, resulting from the implementation of MR-based collaborative learning.

2.2. Activity Procedure

This study adopts a participatory-collaborative approach, in which teachers and students are actively involved throughout the research process, from the initial needs assessment to the evaluation of the Mixed Reality (MR)-based learning media. This approach is intended to ensure that the developed learning system is contextually relevant, user-centered, and aligned with actual classroom needs. In this approach, teachers act not only as end users but also as co-design participants who contribute to identifying learning challenges, providing feedback during the development phase, and evaluating the usability and pedagogical relevance of the system. Students, on the other hand, are involved as primary users whose interactions, engagement, and responses form the basis for evaluating the effectiveness of the learning media. The participatory-collaborative approach has been widely recognized as an effective method in educational research, particularly in designing technology-enhanced learning environments. Previous studies emphasize that involving teachers in the design process improves the relevance and applicability of educational technologies [14], while collaborative engagement with learners enhances both digital literacy and social interaction [15]. In addition, participatory training models have been shown to strengthen teachers' capacity in integrating instructional media [16], and participatory design approaches can foster student engagement and learning motivation in technology-supported environments [17]. By integrating participatory principles within a collaborative learning framework, this study ensures that the implementation of MR-based learning media is not only technically feasible but also pedagogically meaningful and sustainable in real classroom settings.

2.3. Research Procedure

The research procedure follows the stages illustrated in Figure 2 and is systematically structured into four main phases: needs assessment, design and development, implementation, and evaluation. This structured process ensures a coherent alignment between the development of the MR-based learning media and its evaluation in a real classroom context.

The first phase, needs assessment, was conducted through Focus Group Discussions (FGD) involving teachers to identify learning challenges related to the solar system topic and to determine the requirements for the development of the learning media. This phase provides a contextual foundation for designing a solution that is relevant to classroom needs. The second phase involves the design and development of the Mixed Reality (MR)-based learning media. In this stage, the system was developed by integrating immersive visualization with multiplayer features to support collaborative learning. The learning content was designed in accordance with the elementary school curriculum to ensure its pedagogical relevance. The third phase is the implementation stage, which involves beta testing of the developed system in a real classroom setting. During this phase, students and teachers interact directly with the MR application, allowing observation of user engagement, interaction patterns, and system usability in practice. The final phase is the evaluation stage, which is conducted using a mixed-method approach as shown in Figure 2. Quantitative data were collected through structured questionnaires administered to students and teachers, while qualitative data were obtained through classroom observations and interviews. This phase aims to evaluate usability, student motivation, conceptual understanding, and collaborative interaction resulting from the implementation of the MR-based learning media.

2.4. Data Collection Methods

Data in this study were collected using a mixed-method approach, combining quantitative and qualitative techniques to obtain a comprehensive understanding of the effectiveness of the MR-based learning media [8]. The data collection process involved questionnaires, classroom observations, and interviews. Quantitative data were collected through structured questionnaires administered to students and teachers after the implementation of the learning media [18]. The questionnaire items were designed to measure key variables, including usability, learning motivation, conceptual understanding, interaction, and student engagement. A Likert scale was used to capture participants' responses, enabling the analysis of perception-based data in a measurable form.

The participants involved in the data collection consisted of 37 students and 8 teachers, following a data cleaning process to remove duplicate and invalid responses. The selection of participants was based on their direct involvement in the implementation of the MR-based learning media, ensuring that the collected data were relevant to the research objectives. Qualitative data were obtained through classroom observations and semi-structured interviews. Classroom observation was conducted to capture student interaction, engagement, and collaborative behavior during the learning process, while interviews with teachers were used to gain deeper insights into usability, pedagogical relevance, and the overall learning experience. The combination of quantitative and qualitative data collection methods enables methodological triangulation, providing a more comprehensive and reliable evaluation of both cognitive and social aspects of learning. Prior to analysis, the collected data were subjected to a data cleaning process to remove duplicate and invalid responses. In addition, responses with missing values were handled appropriately depending on the type of analysis conducted.

2.5. Instrument Validity and Reliability

The validity and reliability of the research instruments were evaluated to ensure the accuracy and consistency of the data collected in this study. The questionnaire used in this research was developed based on key variables, including usability, learning motivation,

 https://doi.org/10.12928/spekta.v7i1.15745

conceptual understanding, interaction, and student engagement, as described in the data collection process. Content validity was established through expert judgment involving teachers who participated in the Focus Group Discussion (FGD) during the needs assessment phase. Their feedback was used to refine the questionnaire items to ensure that they were relevant, clear, and aligned with the learning objectives and classroom context. To assess the internal consistency of the instrument, a reliability test was conducted using Cronbach's Alpha, where a value above 0.70 is generally considered acceptable. In conducting the reliability analysis, responses with sufficient completeness were included, while missing values were handled using mean substitution to avoid significant data loss.

Table 1. Reliability Analysis Results

Instrument	Number of Items	Cronbach's Alpha	Interpretation
Student Questionnaire	8	0.921	Excellent
Teacher Questionnaire	5	0.821	Good

The results of the reliability analysis are summarized in Table 1. The student questionnaire achieved a Cronbach's Alpha value of 0.921, indicating excellent internal consistency. Meanwhile, the teacher questionnaire yielded a Cronbach's Alpha value of 0.821, indicating good reliability. These results demonstrate that the instrument used in this study is reliable for evaluating the effectiveness of the MR-based learning media in supporting student interaction and technological literacy.

2.6. Data Analysis Techniques

The data analysis in this study was conducted using both quantitative and qualitative techniques to provide a comprehensive evaluation of the MR-based learning media. This approach allows for a more in-depth understanding of both measurable outcomes and contextual learning experiences. Quantitative data obtained from the questionnaires were analyzed using descriptive statistical methods, including the calculation of mean scores and percentage distributions for each variable. These analyses were used to assess key aspects such as usability, learning motivation, conceptual understanding, interaction, and student engagement. In addition, a reliability analysis using Cronbach's Alpha was performed to evaluate the internal consistency of the questionnaire items [19]. Qualitative data collected through classroom observations and interviews were analyzed using a thematic analysis approach. The data were systematically reviewed to identify recurring patterns related to student interaction, engagement, collaboration, and learning experiences during the implementation of the MR-based learning media. To enhance the validity of the findings, methodological triangulation was applied by integrating the results from both quantitative and qualitative analyses [20]. This process enables cross-verification of findings and provides a more comprehensive interpretation of the effectiveness of the learning media. By combining statistical analysis with qualitative insights, this study ensures that both cognitive outcomes and social interaction aspects are adequately captured and evaluated.

3. Results and Discussion

3.1. Authors and Affiliations

This section presents and analyzes the findings of the study on the implementation of Mixed Reality (MR)-based solar system learning media with multiplayer features in an elementary school context. The analysis focuses on evaluating the effectiveness of the developed system in enhancing student interaction, technological literacy, and conceptual understanding of the solar system. The findings are derived from a combination of quantitative and qualitative data, including questionnaire responses from 37 students and 8 teachers, classroom observations, and Focus Group Discussions (FGD). The analysis integrates descriptive statistical results and qualitative insights to provide a comprehensive evaluation of both cognitive and social learning outcomes. The discussion is organized into three main parts: (1) findings from the needs assessment through FGD, (2) implementation of the MR-based learning media in a classroom setting, and (3) descriptive analysis of user responses to evaluate the effectiveness of the learning media.

3.2. Needs Assessment Findings

The initial findings of this study were derived from the needs assessment phase conducted through Focus Group Discussions (FGD) with teachers. The results reveal several limitations in the previously developed learning media used in the 2024 PKM implementation, particularly in supporting interactive and collaborative learning. Teachers reported that although Augmented Reality (AR)-based learning media was accessible and easy to use via smartphones, it lacked immersive depth and did not sufficiently support student interaction. This finding is consistent with previous work [21], which demonstrated that AR-based learning media can enhance usability and basic understanding but remains limited in providing interactive learning experiences. Similarly, earlier research on immersive learning media [22] indicated that while XR-based systems offer engaging visualizations, they often lack mechanisms to support meaningful collaboration among students. Several key challenges were identified from the FGD results. First, the existing media did not adequately visualize dynamic astronomical concepts, such as planetary rotation, revolution, and relative motion. Second, there was a lack of comparative representation of planetary characteristics, which limited students' ability to understand abstract relationships within the solar system. Third, the absence of integrated evaluation features, such as collaborative quizzes, reduced opportunities for active learning and knowledge reinforcement. Most importantly, the previous system did not facilitate interaction among students, resulting in a predominantly individual learning experience despite the use of immersive technology [23]–[25].

Based on these findings, the development of the MR-based learning media in this study was directed toward addressing these limitations by integrating multiplayer features to enable real-time interaction among students and teachers. This design aims to transform the learning process from passive visualization into an interactive and collaborative experience. The inclusion of shared virtual environments, discussion opportunities, and interactive tasks is expected to enhance both conceptual understanding and social engagement. Furthermore, teacher involvement emerged as a critical factor in ensuring the effectiveness and sustainability of the system. Teachers expressed the need to actively participate not only as users but also as facilitators who guide and support collaborative learning activities. This aligns with the participatory-collaborative approach adopted in this study, where teachers contribute to both

 https://doi.org/10.12928/spekta.v7i1.15745

the design and implementation process. Overall, the needs assessment findings highlight a fundamental shift from visualization-centered learning toward interaction-driven learning. These findings serve as the basis for the development of a collaborative MR-based learning model that integrates immersive technology with social interaction, aiming to improve both cognitive and affective learning outcomes in elementary science education.

3.3. Implementation of MR-Based Learning Media

The MR-based learning media was implemented in a real classroom setting to evaluate its feasibility and effectiveness in supporting collaborative learning. The system was designed to enable simultaneous interaction among students and teachers within a shared immersive environment, allowing users to explore and discuss solar system concepts collectively rather than individually. To support real-time interaction, a network architecture was developed to ensure synchronization among multiple devices during the learning process [26]–[28]. As illustrated in Figure 3, the system utilizes a centralized network configuration that enables stable communication between users, allowing synchronized visualization and interaction within the MR environment. This infrastructure plays a crucial role in enabling multiplayer functionality, where users can interact with virtual objects and with each other in real time.

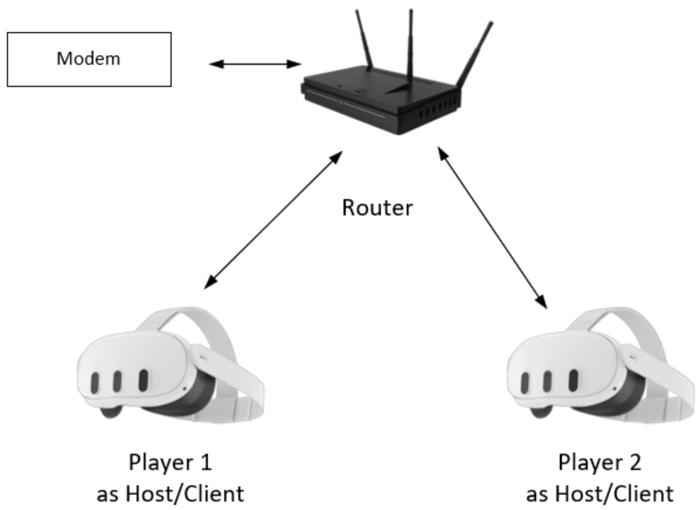

Figure 3. Network architecture supporting real-time collaborative interaction in the MR-based learning environment

The MR system provides an immersive visualization of the solar system, allowing users to interact directly with planetary objects through intuitive gestures and shared exploration. As shown in Figure 4, the MR environment enables users to observe planetary characteristics, spatial relationships, and dynamic movements such as rotation and revolution. This interactive visualization supports experiential learning, where abstract scientific concepts become more concrete and easier to understand through direct manipulation.

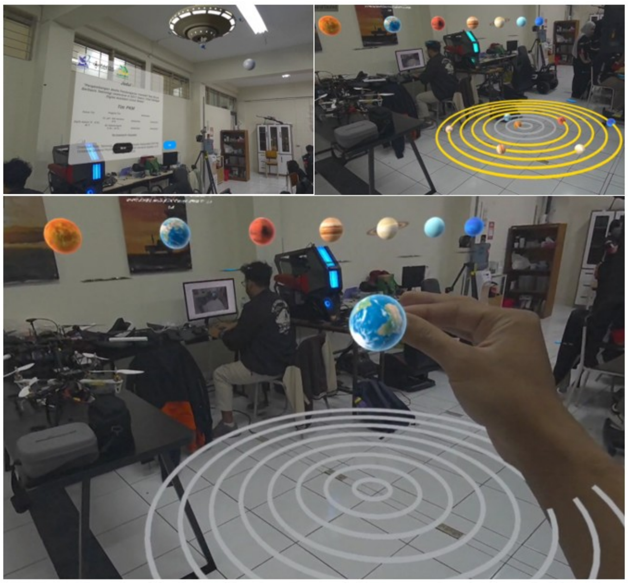

Figure 4. Immersive MR-based visualization of the solar system enabling interactive exploration

The implementation was carried out in a classroom setting involving both students and teachers, where the system was used as a medium for collaborative learning activities. As illustrated in Figure 5, students and teachers actively engaged in shared learning experiences, including discussion, exploration, and explanation of solar system concepts within the MR environment. This interaction demonstrates the practical feasibility of integrating MR technology into classroom learning and highlights the transition from individual learning to collaborative knowledge construction.

Figure 5. Classroom implementation of MR-based learning showing collaborative interaction among students and teachers

In addition to system implementation, teacher involvement played a significant role in ensuring effective usage of the MR-based learning media. Teachers participated in initial system familiarization and guided students during the learning process, facilitating interaction and discussion. This involvement reflects the importance of teacher readiness in supporting technology-enhanced learning environments, where teachers act not only as instructors but

 https://doi.org/10.12928/spekta.v7i1.15745

also as facilitators of collaborative learning. Overall, the implementation results indicate that the MR-based learning media is both technically feasible and pedagogically effective in supporting interactive and collaborative learning. The integration of immersive visualization, real-time synchronization, and teacher facilitation creates a learning environment that encourages active participation, enhances conceptual understanding, and promotes social interaction among students, which is consistent with previous findings on collaborative immersive learning environments [8], [10], [17].

3.4. Descriptive Analysis of Learning Outcomes

This section presents the quantitative and qualitative findings to evaluate the effectiveness of the MR-based learning media in enhancing student learning outcomes. The analysis is based on questionnaire responses from 37 students and 8 teachers, which were obtained after data cleaning and validation. The descriptive analysis focuses on several key variables, including learning motivation, conceptual understanding, usability, confidence, and student engagement. These variables were selected to capture both cognitive and affective aspects of the learning experience. The distribution of respondents is summarized in Table 2, showing the composition of students and teachers involved in this study.

Table 2. Respondent Distribution

Respondent	Number	Proportion
Teachers	8	17.78%
Students	37	82.22%
TOTAL	45	100%

The results of teacher responses regarding the usability and effectiveness of the MR-based learning media are presented in Table 3. Overall, teachers reported positive perceptions, particularly in terms of system usability, relevance to learning objectives, and its ability to support student interaction. These findings indicate that the system is feasible for classroom implementation and aligns well with instructional needs.

Table 3. Teacher Responses on the Effectiveness of MR-based learning media

Indicator	Very Appropriate (%)	Appropriate (%)	Moderately Appropriate (%)	Less Appropriate (%)	Not Appropriate (%)
Ease of SOP usage	25.0	75.0	0	0	0
Suitability of interaction features	25.0	75.0	0	0	0
Improvement of teacher knowledge	37.5	62.5	0	0	0
Effectiveness in improving student understanding	50.0	50.0	0	0	0
Impact of multiplayer features on student engagement	50.0	50.0	0	0	0

The results of teacher responses, as presented in Table 3, indicate a consistently positive evaluation of the MR-based learning media. Most teachers rated the system as appropriate to very appropriate across all indicators. The ease of using the Standard Operational Procedure (SOP) and the suitability of interaction features were positively perceived by 75% of respondents, indicating that the system is manageable within classroom settings. Furthermore, 62.5% of teachers reported an improvement in their technological knowledge after participating in the implementation process, highlighting the role of the system in enhancing teacher digital literacy. In terms of learning effectiveness, all teachers rated the system as appropriate or very appropriate in improving student understanding and engagement. These findings suggest that the MR-based learning media is not only technically feasible but also pedagogically relevant for supporting interactive and collaborative learning.

Student responses further reinforce these findings, as shown in Table 4. The results demonstrate consistently positive responses across all evaluated indicators, suggesting that the MR-based learning media effectively enhances student motivation, conceptual understanding, and engagement. The interactive features of the system allow students to actively participate in the learning process, contributing to a more meaningful learning experience.

Table 4. Student Responses on the Effectiveness of MR-based learning media

Indicator	Very Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
Learning enjoyment after using MR	67.6	32.4	0	0	0
Increased motivation to learn	64.9	35.1	0	0	0
Interest in future MR learning features	62.2	37.8	0	0	0
Understanding of planetary order	70.3	29.7	0	0	0
Ease of identifying planetary characteristics	64.9	35.1	0	0	0
Clarity of information presented	67.6	32.4	0	0	0
Confidence in explaining concepts	56.8	43.2	0	0	0
Comfort in discussion and interaction	62.2	37.8	0	0	0

The results of student responses, as presented in Table 4, indicate a consistently positive perception of the MR-based learning media across all evaluated indicators. A majority of students expressed strong agreement regarding their learning experience, particularly in terms of conceptual understanding and engagement. The highest positive response was observed in students' understanding of planetary order (70.3% strongly agree), followed by learning enjoyment and clarity of information (67.6% strongly agree). These findings suggest that the immersive and interactive features of the MR system effectively support students in understanding abstract scientific concepts, as highlighted in prior immersive learning studies [8], [29].

In addition, students reported increased motivation (64.9% strongly agree) and active participation in discussions (62.2% strongly agree), indicating that the system promotes engagement and collaborative learning, which aligns with previous research emphasizing the

 https://doi.org/10.12928/spekta.v7i1.15745

role of interactive technologies in enhancing student participation [10], [15]. Although slightly lower, confidence in explaining concepts (56.8% strongly agree) still shows a strong positive trend, suggesting that students are developing both cognitive understanding and communication skills. Overall, the absence of negative responses across all indicators highlights the effectiveness of the MR-based learning media in creating an engaging and meaningful learning experience. To provide a more comprehensive evaluation, the mean scores of each variable were calculated, as presented in Table 5.

Table 5. Mean Score of Student Responses Across Variables

Variable	Mean Score (M)	Interpretation
Motivation	4.43	Very High
Understanding	4.44	Very High
Usability	4.40	Very High
Confidence	4.05	High
Engagement	4.31	Very High
Overall	4.36	Very High

The results indicate that all variables fall within the high to very high category, with conceptual understanding (M = 4.44) and learning motivation (M = 4.43) achieving the highest scores. Usability (M = 4.40) and engagement (M = 4.31) also demonstrate strong positive responses, indicating that the system is both accessible and engaging for students. Although slightly lower, the confidence variable (M = 4.05) still falls within the high category, suggesting that students are generally confident in explaining solar system concepts after using the MR-based learning media. Overall, the average score of 4.36 indicates that the MR-based learning media is highly effective in supporting both cognitive and affective learning outcomes.

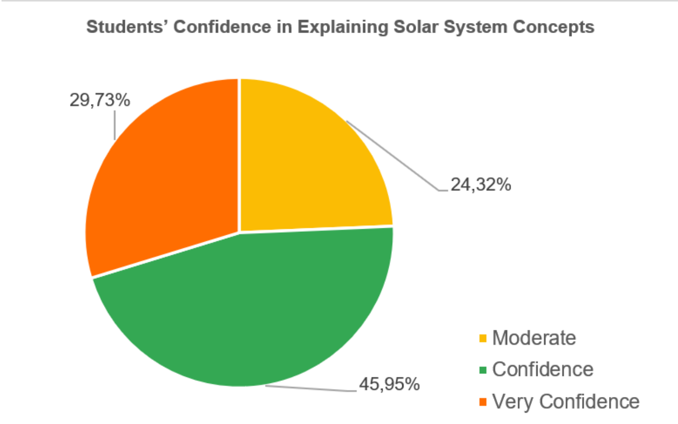

Figure 6. Distribution of Students' Confidence in Explaining Solar System Concepts (n = 37)

In addition to overall evaluation, student confidence in explaining solar system concepts is further illustrated in Figure 6. The distribution shows that the majority of students demonstrate high levels of confidence, indicating that the MR-based learning environment not only improves conceptual understanding but also supports communication and collaborative learning skills, which are essential components of student-centered learning environments [2], [30].

Figure 6 illustrates the distribution of students' confidence in explaining solar system concepts after engaging with the MR-based learning media. The results indicate that the majority of students demonstrate a high level of confidence, with 45.95% categorized as confident and 29.73% as very confident. This suggests that the immersive and interactive features of the MR environment effectively support students in developing not only conceptual understanding but also the ability to communicate scientific knowledge. Meanwhile, 24.32% of students fall within the moderate confidence category, indicating that although most students benefit from the system, some still require additional support or repeated exposure to fully develop their confidence. Nevertheless, the absence of low-confidence responses reflects that the learning environment is generally supportive and encourages active participation. Overall, these findings highlight that the MR-based learning media contributes positively to students' self-confidence, which is an essential component of collaborative learning and active classroom interaction.

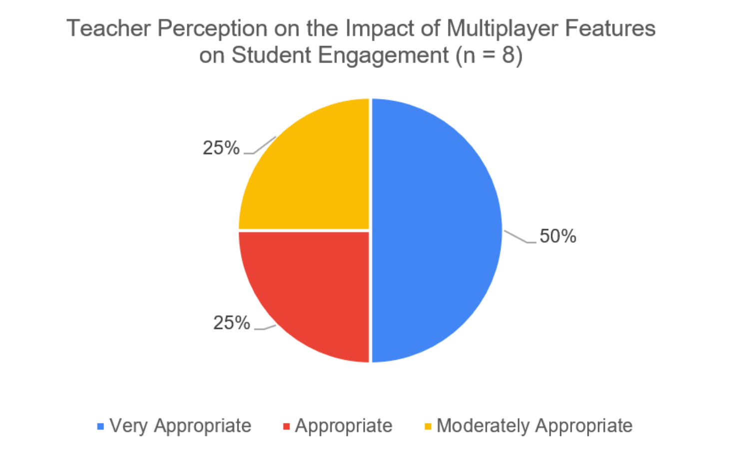

Figure 7. Teacher Perception on the Impact of Multiplayer Features on Student Engagement (n = 8)

Figure 7 presents teachers' perceptions regarding the impact of multiplayer features on student engagement. The results indicate that half of the teachers (50%) rated the feature as very appropriate, while 25% considered it appropriate and another 25% moderately appropriate. This distribution suggests that although most teachers perceive the multiplayer feature positively, there is still variation in perceived effectiveness, indicating opportunities for further refinement and optimization of the system.

Overall, the findings demonstrate that the MR-based learning media provides a meaningful learning experience by integrating immersive visualization with collaborative interaction. This approach not only enhances students' perceived learning outcomes but also supports active participation and communication, reinforcing the role of MR as an effective medium for collaborative learning in elementary education.

 https://doi.org/10.12928/spekta.v7i1.15745

4. Conclusion

This study presented the development and implementation of a Mixed Reality (MR)-based solar system learning media with multiplayer features in an elementary school context. The findings demonstrate that the proposed system effectively supports both cognitive and social aspects of learning. From the students' perspective, the MR-based learning environment enhances motivation, conceptual understanding, engagement, and confidence in explaining scientific concepts. From the teachers' perspective, the system is perceived as usable, relevant to instructional needs, and supportive of classroom interaction. A key contribution of this study lies in the integration of immersive visualization with collaborative interaction through multiplayer features, which transforms the learning experience from individual exploration into a more participatory and interactive process. This approach enables students not only to understand abstract concepts more effectively but also to actively engage in discussion and knowledge sharing within a shared virtual environment.

Furthermore, the participatory-collaborative approach involving teachers throughout the development and implementation stages ensures that the system is contextually relevant and pedagogically meaningful. This involvement also contributes to improving teachers' technological literacy and readiness in adopting immersive learning technologies in classroom settings. These findings are consistent with previous studies indicating that immersive technologies can enhance student engagement and understanding of abstract concepts, and that collaborative features in XR-based learning environments can strengthen motivation and social interaction [10]. In addition, teacher involvement plays a critical role in the successful integration of immersive technologies in education [31]. In conclusion, the MR-based collaborative learning media developed in this study demonstrates strong potential as an effective approach to support interactive, engaging, and meaningful learning in elementary education. Future work may focus on expanding the system to broader learning topics and conducting longitudinal studies to evaluate long-term learning impacts.

Acknowledgement

The authors would like to express their sincere gratitude to the Directorate of Research and Community Service (DPPM) for funding this Community Service Program (PKM DIKTI) in 2025. The authors also acknowledge the support from the Institute for Research and Community Service (LPPM) of ITENAS for their guidance throughout the program. The authors would like to extend their appreciation to Nita Yuliana, the principal of SDIT Daarul Jihad, for her valuable support and collaboration in facilitating the implementation of this study. The authors also thank Ramzi Syuhada for his contribution in supporting the development of the Mixed Reality-based learning system. In addition, the authors are grateful to the teachers and students of SDIT Daarul Jihad for their active participation and valuable feedback.

References

[1] Z. Ersozlu, S. Ledger, A. Ersozlu, F. Mayne, and H. Wildy, "Mixed-Reality Learning Environments in Teacher Education: An Analysis of TeachLivE™ Research," *Sage Open*, vol. 11, no. 3, Jul. 2021, https://doi.org/10.1177/21582440211032155

[2] S. Budin, "Three Approaches to Using Mixed Reality Simulations for Teacher Preparation and Recruitment of Future Teachers," *Educ. Sci.*, vol. 14, no. 1, p. 75, Jan. 2024, https://doi.org/10.3390/educsci14010075

[3] R. Rinda, " Quizizz instructional strategies that consider learners' emotional and cognitive conditions. In special education contexts, conventional teaching approaches often limit student with Special Needs," *JETS J. English Teach. Strateg.*, 2023, https://doi.org/10.47759/ejcgtm14

[4] M. Nurcahyani and E. Sudarmilah, "Augmented reality solar system learning media applications based on Android for elementary school," 2023, p. 040006, https://doi.org/10.1063/5.0141771

[5] D. Nursyaidah, D. Rochintaniawati, N. Winarno, and R. A. Sihombing, "Bringing Space into the Classroom: An AR-Integrated E-Book on the Solar System for Students in Elementary School," *J. Penelit. Pendidik. IPA*, vol. 11, no. 8, pp. 498–507, Aug. 2025, https://doi.org/10.29303/jppipa.v11i8.12562

[6] C. Liu, S. Meng, W. Zheng, and Z. Zhou, "Research on the impact of immersive virtual reality classroom on student experience and concentration," *Virtual Real.*, vol. 29, no. 2, p. 82, May 2025, https://doi.org/10.1007/s10055-025-01153-w

[7] J. Bailenson, *Experience on demand: What virtual reality is, how it works, and what it can do*. books.google.com, 2018.

[8] A. Almufarreh, "Exploring the Potential of Mixed Reality in Enhancing Student Learning Experience and Academic Performance: An Empirical Study," *Systems*, vol. 11, no. 6, p. 292, Jun. 2023, https://doi.org/10.3390/systems11060292

[9] H. Tang, Y. Lin, and Y. Qian, "Understanding K-12 teachers' intention to adopt open educational resources: A mixed methods inquiry," *Br. J. Educ. Technol.*, vol. 51, no. 6, pp. 2558–2572, Nov. 2020, https://doi.org/10.1111/bjet.12937

[10] N. van der Meer, V. van der Werf, W.-P. Brinkman, and M. Specht, "Virtual reality and collaborative learning: a systematic literature review," *Front. Virtual Real.*, vol. 4, May 2023, https://doi.org/10.3389/frvir.2023.1159905

[11] S. Suryani, D. U. Daihani, T. Amran, and W. Septiani, "Systematic Literature Review of Sustainable Assessment Model in Vocational Higher Education," *Spektrum Industri*. 2025, https://doi.org/10.12928/si.v23i2.459

[12] S. S. Astutik and W. S. Jatiningrum, "Designing the Decision Support System to Determine the Major and Higher Education Institution based on Preferences of Prospective Students," *Spektrum Industri*. 2023, https://doi.org/10.12928/si.v21i2.157

[13] N. Huda, R. Adawiyah, and B. Budiman, "Integrating Environmental Character Education and Eco-Enzyme Innovation for Community-Based Waste Management," *SPEKTA (Jurnal Pengabdi. Kpd. Masy. Teknol. dan Apl.*, vol. 6, no. 2, pp. 230–245, Dec. 2025, https://doi.org/10.12928/spekta.v6i2.14387

[14] A. Tuhkala, “A systematic literature review of participatory design studies involving teachers,” *Eur. J. Educ.*, vol. 56, no. 4, pp. 641–659, Dec. 2021, https://doi.org/10.1111/ejed.12471

[15] D. Hardianto and U. A. Wati, “Design of a participatory blended learning model in partnership with schools and parents of elementary school students,” *J. Inov. Teknol. Pendidik.*, vol. 9, no. 3, pp. 355–366, Jan. 2023, https://doi.org/10.21831/jitp.v9i3.57615

[16] M. Muslim, N. Y. Rustaman, P. Siahaan, W. Liliawati, and R. Efendi, “Implementation of Participatory Training Model to Develop Teachers’ Ability to Design Formative Assessment Instruments in Science Learning,” *J. IPA Pembelajaran IPA*, vol. 7, no. 1, pp. 97–107, Mar. 2023, https://doi.org/10.24815/jipi.v7i1.29657

[17] F. Baradaran Rahimi and B. Kim, “The role of interest-driven participatory game design: considering design literacy within a technology classroom,” *Int. J. Technol. Des. Educ.*, vol. 29, no. 2, pp. 387–404, Mar. 2019, https://doi.org/10.1007/s10798-018-9451-6

[18] J. A. Bravo-Cedeño and F. M. Avila-Rosales, “School bullying and learning in high school students,” *Int. Res. J. Manag. IT Soc. Sci.*, vol. 9, no. 4, pp. 631–638, 2022, doi: https://doi.org/10.21744/irjmis.v9n4.2130

[19] W. Osman, J. P. K. Ninnoni, and M. T. Anim, “Use of the nursing process for patient care in a Ghanaian Teaching Hospital: A cross sectional study,” *Int. J. Africa Nurs. Sci.*, vol. 14, 2021, https://doi.org/10.1016/j.ijans.2021.100281

[20] J. Radianti, T. A. Majchrzak, J. Fromm, and I. Wohlgenannt, “A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda,” *Comput. Educ.*, vol. 147, p. 103778, Apr. 2020, https://doi.org/10.1016/j.compedu.2019.103778

[21] G. A. Rakhmat, “Aplikasi Android Mengenal Tata Surya Berbasis Augmented Reality Sebagai Media Belajar Interaktif Siswa Sekolah Dasar,” *Build. Informatics, Technol. Sci.*, vol. 2, no. 2, pp. 151–158, Dec. 2020, https://doi.org/10.47065/bits.v2i2.590

[22] G. Ashari *et al.*, “Pengembangan Media Pembelajaran Tata Surya Berbasis Teknologi Immersive di SDIT Daarul Jihad,” *J. SOLMA*, vol. 14, no. 1, pp. 632–643, Apr. 2025, doi: https://doi.org/10.22236/solma.v14i1.16855

[23] T. Guionnet, M. Raulet, and T. Burnichon, “Forward-looking content-aware encoding for next-generation UHD, HDR, WCG, and HFR,” *SMPTE Motion Imaging J.*, vol. 129, no. 7, 2020, https://doi.org/10.5594/JMI.2020.3001797

[24] J. E. A. Lôbo, W. F. M. Correia, J. M. Teixeira, J. E. de M. Siqueira, and R. A. Roberto, “WebAR as a Mediation Tool Focused on Reading and Understanding of Technical Drawings Regarding Tailor-Made Projects for the Scenographic Industry,” *Appl. Sci.*, vol. 13, no. 22, p. 12295, Nov. 2023, doi: https://doi.org/10.3390/app132212295

[25] J. I. Vallade, “Technology acceptance model: investigating students’ intentions toward adoption of immersive 360° videos for public speaking rehearsals,” *Commun. Educ.*, pp. 1–19, 2020, doi: https://doi.org/10.1080/03634523.2020.1791351

[26] S. Bhatia and A. S. Albarrak, “A Blockchain-Driven Food Supply Chain Management Using QR Code and XAI-Faster RCNN Architecture,” *Sustainability*, vol. 15, no. 3, p. 2579, Jan. 2023, doi: https://doi.org/10.3390/su15032579

[27] S. Masdah, N. P. Mayarestya, N. Nuruniyah, and Budiman, "Education on Utilization of Online Queuing Application Based on Khanza Health Information System for Patients and Families," *SPEKTA (Jurnal Pengabdian Kepada Masyarakat Teknologi dan Aplikasi),"* 2025, https://doi.org/10.12928/spekta.v6i2.14387

[28] B. N. Lee, "Adapting history education for the 21st century: Integrating technology and critical thinking skills," *SPEKTA (Jurnal Pengabdian Kepada Masyarakat Teknologi dan Aplikasi)*, 2023. https://doi.org/10.12928/spekta.v4i2.8572

[29] S. S. Y. Kim, K. M. Huang-Isherwood, W. Zheng, and D. Williams, "The art of being together: How group play can increase reciprocity, social capital, and social status in a multiplayer online game," *Comput. Human Behav.*, vol. 133, p. 107291, Aug. 2022, doi: https://doi.org/10.1016/j.chb.2022.107291

[30] C. M. Stracke, P. Bothe, S. Adler, E. S. Heller, J. Deuchler, and M. Wolfel, "Immersive virtual reality in higher education: a systematic review of the scientific literature," *Virtual Reality*. Springer, 2025, https://doi.org/10.1007/s10055-025-01136-x

[31] N. Alalwan, L. Cheng, H. Al-Samarraie, R. Yousef, A. Ibrahim Alzahrani, and S. M. Sarsam, "Challenges and Prospects of Virtual Reality and Augmented Reality Utilization among Primary School Teachers: A Developing Country Perspective," *Stud. Educ. Eval.*, vol. 66, p. 100876, Sep. 2020, https://doi.org/10.1016/j.stueduc.2020.100876