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The Effectiveness of Augmented Reality-Based Learning Media on Students' Conceptual Understanding of Science and Social Studies in the Solar System Topic at SDN Sanding 2

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Abstract. Students' conceptual understanding of Natural Sciences and Social Sciences (IPAS) on the topic of the solar system is still low due to the dominance of conventional, non-interactive learning media. This condition highlights the need for technological innovations that provide contextual and engaging learning experiences. This study aims to test the effectiveness of Augmented Reality (AR)-based learning media in improving students' conceptual understanding. This study uses a quantitative approach with a quasi-experimental design, involving two sixth-grade classes at SDN Sanding 2, Petir District, with a total of 60 students. The experimental class used AR media, while the control class used conventional 2D images. Data were collected through pretest and posttest assessments. Data were analyzed using an independent t-test to determine the difference in the average score increase between the experimental and control groups, after first conducting a normality and homogeneity prerequisite test. The results of the independent t-test show that t_count = 5.92 > t_table = 2.00 with a p-value of 0.000, indicating a significant difference between the two groups. The average conceptual understanding score in the experimental class increased by 18.6 points, compared to 6.4 points in the control class. These findings indicate that Augmented Reality-based learning media effectively improves conceptual understanding and student engagement in learning about the solar system in elementary education.

Keywords: Augmented Reality, Learning Media, Science and Social Studies, Conceptual Understanding.

INTRODUCTION

Science and Social Studies (IPAS) learning in elementary schools plays a pivotal role in cultivating scientific reasoning and strengthening students' understanding of concepts relevant to everyday life. Among the materials taught, the Solar System is particularly challenging because it involves abstract and unobservable phenomena. Despite this, classroom practice at the elementary level remains dominated by conventional learning media such as static two-dimensional pictures, teacher lectures, and textbook descriptions. These approaches are often insufficient in stimulating curiosity, reducing cognitive load, or supporting meaningful conceptual construction among students (Ningsih, 2019). As a result, students' conceptual understanding of Solar System material remains low, indicating a persistent instructional problem that needs to be addressed.

A major factor contributing to this low conceptual mastery is the limited opportunity for students to engage in contextual and visual learning experiences. Many learners struggle to imagine the relative size, distance, and movement of celestial bodies, leading them to memorize facts without meaningful comprehension (Qian and Choi, 2023). This situation demonstrates a clear research gap—the lack of interactive, visual, and immersive learning tools that can help

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translate abstract scientific ideas into perceptible learning experiences. Although the need for such media has been acknowledged, the implementation of innovative tools in primary schools is still minimal, particularly for IPAS topics that rely heavily on visualization such as the Solar System.

One promising innovation that can minimize this gap is the integration of Augmented Reality (AR) into instructional media. AR technology merges real-world elements with digitally generated objects, allowing students to interact directly with three-dimensional representations of the concepts being studied (Mansour et al., 2025). Unlike traditional visual aids, AR supports exploration, manipulation, and inquiry, enabling students to observe phenomena that are otherwise invisible or difficult to conceptualize. This interaction is expected to increase curiosity, improve conceptual understanding, and enhance student engagement during learning.

The use of AR-based media also aligns with the orientation of the Merdeka Curriculum, which emphasizes technology-supported learning, exploration, and the development of higher-order thinking skills. As students engage with AR simulations, they learn not only scientific content but also collaboration, communication, and digital competencies that are essential in the 21st century (Kemendikbudristek, 2022; Pamorti and Suryandari, 2024). However, although international studies have shown the benefits of AR in improving motivation, understanding, and learning achievement (Pamorti and Suryandari, 2024; Wiliyanti et al., 2024), the application of this technology at the elementary level in Indonesia—specifically in teaching IPAS Solar System content—has not been widely explored. This limited implementation further strengthens the need for research that evaluates AR within authentic classroom settings.

From a theoretical perspective, AR functions as a bridge between abstract knowledge and experiential learning. Mansour et al. (2025) highlight that AR supports learners in visualizing scientific concepts that cannot be observed directly, a capability particularly valuable for students in Piaget's concrete operational stage. Through AR, learners can construct mental models by exploring digital simulations that resemble real-world systems. In addition, AR promotes inquiry-based and self-regulated learning because students must plan, observe, manipulate, and evaluate during their interactions with AR content (Lavrysh et al., 2023). These cognitive processes contribute not only to deeper understanding but also to the development of metacognitive awareness.

The Indonesian educational context adds another layer to the research gap. Despite policy support for digital learning, many elementary schools—especially those in rural or resourcelimited areas—have minimal exposure to interactive technologies. Surveys indicate that fewer than 30% of teachers in such schools have ever used AR or 3D visualization tools in classroom practice (Alalwan et al., 2020). This shows that the lack of access to effective digital media remains a systemic issue that widens the learning gap between schools. Therefore, examining AR as a potentially equitable learning intervention is not only academically relevant but also socially significant.

Given these theoretical, empirical, and contextual considerations, this study aims to evaluate the effectiveness of AR-based instructional media in enhancing fourth-grade students' conceptual understanding of IPAS Solar System material at SDN Sanding 2. Unlike many previous studies that relied on laboratory settings or small-scale trials, this research is conducted directly in a real classroom environment. Therefore, the results are expected to contribute deeper insights into the pedagogical affordances of AR while offering practical recommendations for curriculum implementation in Indonesian elementary schools.

Moreover, the incorporation of AR reflects a pedagogical transformation that resonates with constructivist and experiential learning principles. AR encourages students to build knowledge through exploration and discussion rather than passive reception. This shift supports the development of collaborative, analytical, and creative abilities, which are essential for navigating complex scientific concepts and meeting the demands of the digital era (Dole et al., 2016). Through shared interactions with AR simulations, students negotiate meaning together, refine their understanding, and strengthen communication skills. Consequently, AR is not merely a technological enhancement but a strategic instructional approach that fosters holistic learning in IPAS education.

Although the potential of AR in science education has been widely acknowledged, its application within elementary IPAS instruction still faces several methodological and pedagogical challenges that remain underexplored. Many prior studies focus predominantly on the technical development of AR media, while its influence on classroom dynamics, teacher readiness, and students' concept-building processes in authentic learning environments has received less comprehensive attention. In reality, the effectiveness of instructional technology is determined not only by its visual quality or interactive features but also by its alignment with learners' needs and teachers' ability to orchestrate technology-supported learning experiences. Therefore, this study offers a meaningful contribution by examining AR not merely as a visualization tool, but as an integral component of instructional practice—one that must account for classroom context, learner characteristics, and instructional design to support deeper conceptual understanding.

In summary, this study is expected to enrich the development of innovative learning media and provide evidence-based guidance for educators seeking to integrate digital technology into IPAS instruction at the elementary level. By addressing the explicit research gap—the limited use of AR in primary IPAS learning and the lack of empirical studies in real classroom settings, this research contributes to advancing both academic discourse and practical implementation in Indonesian education.

METHODOLOGY

This study employed a quantitative research approach using a quasi-experimental Nonequivalent Control Group Design. This design was selected because the assignment of participants to the experimental and control groups could not be carried out randomly; instead, the groups were determined based on intact classroom units that already existed in the school setting (Sari et al., 2025). The research took place at SDN Sanding 2, located in Petir District, Serang Regency, during the odd semester of the 2025–2026 academic year. Two fourth-grade classrooms, each consisting of thirty students, were involved as research subjects. Class IV-B was designated as the control group and received instruction using two-dimensional (2D) visual materials, while Class IV-A served as the experimental group and learned using Augmented Reality (AR)-based instructional media. Purposive sampling was used to ensure equivalence between groups by selecting students whose initial competencies, as measured by the pretest, showed comparable starting levels (Arikunto, 2021).

The instrument employed in this research consisted of a conceptual understanding test for the IPAS Solar System topic. The test comprised twenty multiple-choice items and five short-essay questions designed to measure indicators of conceptual understanding, including the ability to classify celestial objects, describe planetary motion, and relate Earth's rotation and revolution to daily-life phenomena, as adapted from Anderson and Krathwohl's taxonomy in Leslie (2016). Before administration, the instrument underwent expert validation involving two content specialists and one learning evaluation expert, who examined the test items for content relevance, construct coherence, and linguistic clarity. Following this expert review, empirical validation was conducted using the Pearson Product Moment correlation to assess item validity, while reliability was determined using Cronbach's Alpha.

Based on the empirical analysis, 22 out of the 25 items met the validity criteria, while 3 items were removed because their calculated correlation values (r_hitung) were below the critical value of r_tabel = 0.361. Reliability testing produced a Cronbach's Alpha coefficient of 0.82, indicating high reliability and strong internal consistency (Izah et al., 2023). Table 1 summarizes the results of the validity and reliability analyses.

Tabel. 1 Results of the Validity and Reliability Test of the Concept Understanding Test Instrument

Type of Test	Number of Items Tested	Valid Items	Dropped Items	Coefficient Value	Category
Validity	25	22	3	rtable = 0.361	Valid
Reliability	25	–	–	α = 0.82	High

The data collection procedures were organized to maintain consistency and minimize the influence of extraneous variables. Both the experimental and control groups were taught by the same teacher to avoid instructional bias. Prior to the intervention, the teacher received structured training on AR media operation and standardized instructional procedures to ensure uniformity throughout the treatment sessions. Additionally, observation protocols were applied systematically during learning to document student engagement indicators, including attention to task, verbal participation, curiosity-driven questions, and interactions with the learning materials. These qualitative engagement metrics served as supporting evidence that complemented quantitative outcomes.

In addition to quantitative measures, qualitative observations were employed to contextualize changes in student performance. While pretest and posttest scores captured cognitive gains, the accompanying observational notes documented behavioral indicators—such as enthusiasm during AR interactions, peer collaboration, and sustained focus—which helped explain how and why conceptual understanding improved (Zhang et al., 2021). This mixed perspective strengthened the interpretive power of the findings by linking instructional processes with measured outcomes.

To ensure data integrity, all test responses were carefully verified prior to analysis. Outliers were examined through boxplot inspection, and questionable responses were rechecked to avoid analytical distortions. Data normality and homogeneity were assessed as prerequisites for conducting parametric tests. The main statistical test used was the independent samples t-test, which compared conceptual understanding gains between the control and experimental groups (Parinduri et al., 2017). Additionally, effect size calculations were conducted using Cohen's d to determine the magnitude of the AR intervention's impact. A value of d greater

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than 0.8 was interpreted as a large effect, indicating substantial improvement attributable to the intervention (Sasmita et al., 2020).

The intervention was conducted in three phases: pretest, treatment, and posttest. The pretest assessed students' baseline conceptual understanding. During the treatment phase, the experimental group interacted with AR-based learning materials featuring interactive 3D Solar System simulations, whereas the control group used conventional 2D images. The intervention occurred over four learning sessions, each lasting 2 hours and 35 minutes. At the conclusion of the treatment period, both groups completed a posttest to measure improvements in conceptual understanding. Observational data collected during these sessions helped link student engagement patterns with achievement outcomes, addressing the need for a clearer connection between behavioral indicators and cognitive gains.

Although the quasi-experimental nature of the study limits the ability to fully control for external variables, internal validity was strengthened through equivalent pretest scores, consistent instructional delivery, and the homogeneous characteristics of the two class groups. The comprehensive methodological framework—combining validation procedures, controlled data collection, and complementary qualitative evidence—ensures that the conclusions drawn from this research are both statistically robust and pedagogically meaningful.

RESULTS AND DISCUSSION

A total of sixty fourth-grade students from SDN Sanding 2 were involved in this research, divided evenly into two learning groups. Thirty students from class IV-A were assigned as the experimental group, while thirty students from class IV-B served as the control group. An analysis of respondent characteristics based on gender showed that both groups had a relatively proportional composition. The experimental class consisted of 14 male and 16 female students, while the control class comprised 13 male and 17 female students. This balanced distribution indicates that gender was not a confounding variable affecting learning outcomes, ensuring that differences in achievement were attributable to the type of learning media implemented.

Table 2. Characteristics of Respondents Based on Gender

Class	Gender	Frequency (n)	Percentage (%)
Experimental	Male	14	46.7
Experimental	Female	16	53.3
Control	Male	13	43.3

Class	Gender	Frequency (n)	Percentage (%)
Control	Female	17	56.7
Total	–	60	100

Learning activities in the experimental group utilized Augmented Reality (AR) to explore concepts related to the Solar System. Students interacted with three-dimensional planetary models through an AR application accessed via mobile devices. Observation notes recorded active student engagement, particularly when exploring spatial characteristics and relative positions of planets. Figure 1 presents an example of these learning activities.

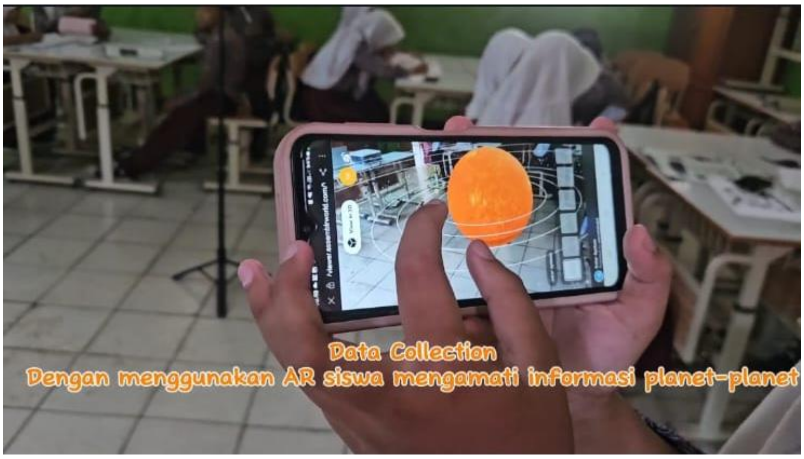

Figure 1. Student Activities Using AR Media to Observe Information About the Planets

Pretest and posttest scores revealed substantial differences between the two groups. The experimental class, which used AR-based media, achieved an average pretest score of 61.2, which increased markedly to 79.8 after instruction—an improvement of 18.6 points. In contrast, the control class using traditional 2D images improved from 60.7 to 67.1, achieving a more modest gain of 6.4 points.

Table 3. Mean Pretest and Posttest Scores of Conceptual Understanding

Class	Mean Pretest	Mean Posttest	Improvement (Gain)
Experimental	61.2	79.8	18.6
Control	60.7	67.1	6.4

The sharper increase in the experimental group clearly demonstrates that AR media substantially enhance students' conceptual understanding. The interactive and immersive

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features of AR allow learners to bridge the gap between abstract scientific ideas and concrete mental representations, making the Solar System more accessible and intuitive.

Normality testing using the Kolmogorov-Smirnov method was conducted prior to hypothesis testing. All obtained significance values were greater than 0.05, indicating that both pretest and posttest data in the two groups were normally distributed.

Table 4. Normality Test Results

Class	Sig. Value (Pretest)	Sig. Value (Posttest)	Description
Experimental	0.200	0.136	Data are normally distributed
Control	0.164	0.102	Data are normally distributed

Homogeneity testing using Levene's Test showed significance values of 0.317 for the pretest and 0.241 for the posttest. As both values exceeded the 0.05 threshold, the data met the homogeneity assumption.

Table 5. Homogeneity Test Results

Data Type	Sig. Value	Description
Pretest	0.317	Homogeneous
Posttest	0.241	Homogeneous

Since the assumptions of normality and homogeneity were satisfied, an independent samples t-test was employed to compare posttest outcomes between the two groups. The analysis yielded a tcount value of 5.92, surpassing the ttable value of 2.00 at α = 0.05. Furthermore, the Sig. (2-tailed) value of 0.000 confirmed a highly significant difference in posttest performance.

Table 6. Independent t-Test Result

Data Type	tcount	ttable (α = 0.05)	Sig. (2-tailed)	Description
Posttest	5.92	2.00	0.000	There is a significant difference

These statistical findings affirm that AR-based instruction leads to significantly better conceptual understanding compared to 2D visual learning. The results reinforce the argument of Mansour (2025), who emphasized that AR allows learners to experience abstract scientific objects in a more realistic and concrete form, thereby deepening conceptual comprehension that is difficult to achieve through conventional media.

The experimental group's gain of 18.6 points supports the notion that technology-enhanced learning can create meaningful and engaging scientific experiences. This aligns with findings by Liu et al. (2023), who reported that AR not only improves conceptual mastery but also boosts motivation through dynamic and interactive content. The ability to manipulate 3D objects enables students to engage in exploratory learning, allowing them to visualize planetary shapes, distances, and motions more accurately, ultimately strengthening cognitive connections.

From a theoretical perspective, the results correspond with constructivist principles, which posit that students learn best through active involvement and interaction with their environment. According to Piaget's view as cited in (Slavin, 2023), direct manipulation of objects supports cognitive restructuring and the assimilation of new ideas. AR shifts students' learning roles from passive listeners to active explorers who construct knowledge through observation, experimentation, and reflection.

The integration of AR media also aligns with the goals of the Merdeka Curriculum, which encourages technology-driven, experience-oriented learning. Through AR, teachers can design IPAS lessons that foster creativity, collaboration, and 21st-century competencies such as digital literacy, critical thinking, and problem-solving (Kemendikbudristek, 2022).

Observation data further show behavioral distinctions between the two groups. Students in the AR class demonstrated higher curiosity, engaged more in peer discussion, and explored planetary models beyond what was required. These behaviors resonate with Self-Determination Theory, which suggests that autonomy, competence, and relatedness are essential for sustained motivation (Wang et al., 2019). AR-supported activities fulfill these psychological needs by enabling self-paced discovery, collaborative exploration, and immediate visual feedback.

Qualitative findings also revealed that students using AR more frequently verbalized connections between concepts, such as relating Earth's rotation to changes in time. This spontaneous reasoning suggests that AR encourages deeper cognitive processing and supports conceptual restructuring. Comparable results were reported by Nhan et al. (2022), who found that AR facilitates experiential learning that enhances students' conceptual coherence.

The magnitude of improvement in this study also mirrors outcomes reported in other STEM fields. Hasanah et al. (2024) found a similar gain of 17.9 points in physics learning using AR.

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Thus, the present study not only reinforces existing evidence but extends its application to the integrated IPAS curriculum.

Beyond cognitive gains, AR's influence on affective and social dimensions is also noteworthy. Students expressed greater enthusiasm, reduced anxiety, and heightened engagement, contributing to a more positive classroom atmosphere. These affective improvements are essential in sustaining long-term interest in science learning and promoting positive academic behavior.

Overall, the findings of this study confirm that the use of Augmented Reality media in elementary IPAS learning significantly enhances conceptual understanding while fostering an active, interactive, and context-rich learning experience. AR proves to be a powerful tool that not only improves academic performance but also cultivates curiosity, motivation, and meaningful scientific inquiry among young learners.

In addition to these findings, the present study highlights the broader pedagogical implications of integrating AR into elementary science classrooms. The technology not only facilitates the delivery of complex spatial concepts but also supports differentiated learning by accommodating various learning styles, including visual, kinesthetic, and exploratory preferences. Students who typically struggle with abstract scientific ideas benefited from the concrete visualizations offered by AR, suggesting that such media can help reduce conceptual gaps among diverse learners. Furthermore, AR encourages a more student-centered learning culture in which learners take initiative, pose questions, and engage in inquiry-driven tasks. This shift reflects contemporary educational priorities that emphasize inclusivity, personalization, and the cultivation of independent scientific thinking. As AR tools continue to develop, their potential to transform elementary science instruction becomes increasingly significant, offering opportunities for richer learning experiences that traditional media cannot fully provide.

CONCLUSION

The findings of this study reaffirm that Augmented Reality (AR)-based learning media substantially enhance students' conceptual understanding of Solar System content in the IPAS subject for fourth-grade learners at SDN Sanding 2. Students who engaged with AR materials consistently demonstrated higher achievement gains than those relying on conventional 2D visual learning. These results indicate that AR's ability to present abstract scientific phenomena in an immersive and interactive format plays a vital role in deepening comprehension and reinforcing cognitive connections that are often difficult to establish through traditional instructional media. Consequently, AR can be regarded as a viable and innovative alternative for strengthening conceptual learning in primary science education.

Moreover, the study highlights that AR is not only cognitively beneficial but also capable of fostering a more engaging, motivating, and exploratory learning environment. By enabling students to manipulate three-dimensional objects and observe dynamic planetary interactions, AR transforms the learning process from passive reception into active knowledge construction. This aligns well with contemporary educational paradigms that emphasize student-centered, inquiry-driven, and experience-based learning. The integration of AR further contributes to positive classroom dynamics by promoting curiosity, peer collaboration, and meaningful dialogue around scientific concepts.

In terms of practical implications, the study underscores the importance of establishing clear, scalable strategies for classroom implementation. Schools should adopt structured guidelines for AR integration, including the selection of appropriate AR applications, the preparation of devices, and the alignment of AR activities with curriculum competencies. To maximize instructional impact, teachers require systematic professional development that equips them not only with technical proficiency but also with pedagogical strategies for embedding AR meaningfully within lesson designs. Training programs should emphasize lesson planning, classroom management with digital tools, and approaches for supporting diverse learners through AR-enhanced activities.

From a policy perspective, the findings call for broader institutional support to ensure equitable access to immersive technology across schools. Investments in digital infrastructure, such as stable internet connections, adequate device availability, and maintenance systems, are essential for sustaining AR-based instructional innovations. Policymakers should also consider integrating AR into national digital learning initiatives and promoting cross-school collaborations to share resources, best practices, and instructional models.

For future research, longitudinal studies are recommended to explore the sustained effects of AR on higher-order skills such as problem-solving, scientific reasoning, and creativity. Mixed-method approaches could provide richer insights into students' emotional experiences, motivation levels, and learning behaviors when using AR over extended periods. Further investigations may also compare different AR platforms or examine hybrid approaches that combine AR with other digital learning tools. Overall, this study highlights the transformative potential of AR to reshape elementary science education and lays the groundwork for its broader and more strategic integration into 21st-century learning environments.

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