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The Effect of Augmented Reality Media on Elementary School Students' Understanding of the Solar System Concept

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Abstract: Comprehending astronomical concepts, such as the solar system, requires high spatial visualization and abstract reasoning, which elementary school students often struggle to develop through static, two-dimensional textbook illustrations. While digital interventions are expanding, empirical insights regarding how Augmented Reality (AR) media can structurally bridge the gap between concrete perception and abstract macro-scientific concepts in early science education remain limited. This study aims to test the effect of augmented reality media on the understanding of the concept of the solar system in elementary school students. Employing a quantitative quasi-experimental design, this study involved 60 sixth-grade students, divided into an experimental class (n = 30, utilizing AR-based media) and a control class (n = 30, utilizing conventional instruction). Quantitative data were gathered via a validated conceptual understanding test and evaluated using descriptive metrics (mean, standard deviation, and learning completeness percentages) alongside paired and independent sample t-tests. The empirical outcomes reveal that AR media exerts a profoundly positive and statistically significant effect on students' conceptual understanding of the solar system. The experimental cohort achieved a vastly superior post-test mean score (92.37) compared to the control group (69.74). Furthermore, a lower standard deviation in the experimental group indicated more equitable knowledge distribution among students, complemented by a staggering 94.02% learning completeness rate against the control group's mere 75.43% ($p < 0.05$). Consequently, AR media serves as a potent pedagogical alternative to mitigate low conceptual comprehension in elementary science. Beyond classroom-level performance, these findings provide critical empirical baseline data for educational tech-developers to design interactive, three-dimensional spatial environments that make complex scientific phenomena accessible to young minds.

Keywords: Augmented reality, conceptual understanding, solar system, elementary science, educational technology.

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INTRODUCTION

The rapid development of digital technology has significantly transformed educational practices across the world. Contemporary educational systems are increasingly integrating digital technologies into classroom instruction to improve learning effectiveness, enhance student engagement, and facilitate deeper conceptual understanding. The integration of technology has become particularly important in science education because many scientific concepts involve abstract phenomena that are difficult for learners to visualize through traditional instructional methods alone (UNESCO, 2023). Consequently, educational institutions are actively exploring innovative technological approaches that can improve students' understanding of scientific concepts and promote meaningful learning experiences.

One of the primary goals of elementary science education is to help students develop a comprehensive understanding of scientific concepts and natural phenomena. Conceptual understanding is widely recognized as a fundamental component of scientific literacy because it enables students to explain, interpret, and apply scientific knowledge in various contexts (National Research Council, 2018). Students who possess strong conceptual understanding are more capable of connecting new information with prior knowledge, solving scientific problems, and making informed decisions based on scientific reasoning.

Despite its importance, developing conceptual understanding remains a major challenge in elementary science education. Many students continue to experience difficulties in understanding abstract scientific concepts because classroom instruction often relies heavily on verbal explanations and static visual representations (Hwang et al., 2022). Such instructional approaches may limit students' opportunities to visualize scientific processes and relationships, resulting in misconceptions and superficial learning outcomes.

The concept of the solar system is among the most challenging science topics taught at the elementary level. Understanding the solar system requires students to comprehend the characteristics of planets, orbital movements, spatial relationships, gravitational interactions, and astronomical phenomena that cannot be directly observed in everyday life (Ibáñez & Delgado-Kloos, 2018). These abstract characteristics frequently create cognitive difficulties for young learners.

Research has shown that elementary school students often develop misconceptions about the solar system due to limitations in visualization and observation opportunities (Plummer et al., 2020). Students may incorrectly perceive planetary sizes, distances, orbital patterns, or the relationships among celestial bodies. Such misconceptions can persist over time and negatively affect subsequent science learning if they are not adequately addressed.

The emergence of educational technology offers new opportunities to overcome these challenges. Advances in digital learning environments have enabled educators to create more interactive and immersive learning experiences that support conceptual understanding. Among the various technologies currently available, Augmented Reality (AR) has attracted considerable attention due to its ability to integrate virtual objects into real-world environments and facilitate interactive learning experiences (Akçayır & Akçayır, 2017).

Augmented Reality refers to a technology that overlays computer-generated information, such as three-dimensional objects, animations, images, videos, and audio, onto the real-world environment in real time (Azuma, 1997). Unlike virtual reality, which immerses users entirely in a virtual environment, augmented reality combines virtual and physical elements, allowing learners to interact simultaneously with digital content and their surrounding environment (Billinghurst et al., 2021).

Educational researchers have increasingly recognized the potential of augmented reality to support learning in science education. By enabling students to visualize abstract concepts in three-dimensional formats, AR can reduce cognitive barriers and enhance conceptual understanding (Garzón et al., 2020). Students can observe scientific phenomena from multiple perspectives, manipulate virtual objects, and engage in exploratory learning activities that are difficult to achieve through conventional instructional approaches.

The theoretical foundation supporting the use of augmented reality in education can be explained through constructivist learning theory. Constructivism suggests that learners actively construct knowledge through interactions with their environment and experiences (Piaget, 1972). Augmented reality facilitates these interactions by providing learners with opportunities to explore and manipulate virtual representations of scientific concepts, thereby promoting active knowledge construction.

In addition to constructivism, the Cognitive Theory of Multimedia Learning proposed by Mayer (2021) provides a strong theoretical basis for augmented reality learning. According to this theory, meaningful learning occurs when learners actively process information through verbal and visual channels. Augmented reality enhances learning by presenting information through multiple sensory modalities, which can improve cognitive processing and facilitate deeper understanding.

The use of augmented reality is also supported by Dual Coding Theory, which suggests that information presented through both visual and verbal representations is more likely to be understood and retained than information presented through a single modality (Paivio, 2014). By integrating textual explanations with interactive three-dimensional visualizations, AR can strengthen students' cognitive representations of scientific concepts.

Recent educational studies have demonstrated positive effects of augmented reality on student learning outcomes. Garzón and Acevedo (2019) found that AR-based learning environments significantly improved students' conceptual understanding and academic achievement compared to traditional instruction. Similar findings were reported by Akçayır and Akçayır (2017), who concluded that AR can enhance learning performance, motivation, and engagement across various educational contexts.

In science education, augmented reality has been particularly effective in supporting the understanding of abstract and complex concepts. Research conducted by Ibáñez et al. (2020) demonstrated that AR-based science learning significantly improved students' comprehension of scientific phenomena by providing realistic and interactive visualizations. These findings suggest that AR may be especially beneficial for topics involving spatial relationships and dynamic processes.

The solar system represents an ideal context for applying augmented reality technology because many astronomical concepts involve objects and processes that are difficult to observe directly. Through AR applications, students can visualize planets rotating around the sun, observe differences in planetary characteristics, and explore celestial movements from various perspectives. Such experiences may facilitate the development of more accurate conceptual understanding (Fleck & Simon, 2019).

Furthermore, augmented reality can increase student engagement and motivation during science learning. Interactive visualizations often stimulate curiosity and encourage active participation, which are important factors influencing conceptual learning (Radianti et al., 2020). Students who are actively engaged in learning activities tend to demonstrate higher levels of attention, persistence, and cognitive investment.

The integration of AR into elementary science instruction is particularly relevant within the context of twenty-first-century education. Contemporary educational frameworks emphasize the importance of technology integration, digital literacy, and student-centered learning approaches (OECD, 2023). Augmented reality aligns closely with these educational priorities because it promotes active exploration, inquiry-based learning, and meaningful interaction with scientific content.

The Indonesian educational context also highlights the importance of innovative science instruction. National curriculum reforms increasingly emphasize scientific literacy, conceptual understanding, and technology-enhanced learning experiences

(Kemendikbudristek, 2022). However, many elementary classrooms continue to rely on conventional teaching methods that may not adequately support the development of deep conceptual understanding.

Several studies conducted in Indonesia have reported that students frequently experience difficulties in understanding astronomy-related concepts, including the solar system (Widodo et al., 2021). These difficulties are often associated with limited access to instructional media capable of visualizing complex astronomical phenomena. Consequently, there is a need for innovative learning media that can make abstract concepts more concrete and accessible.

Although numerous studies have investigated augmented reality in education, several research gaps remain. First, much of the existing literature has focused on secondary schools, universities, or vocational education, while studies involving elementary school students remain relatively limited (Bacca et al., 2018). Given the developmental characteristics of younger learners, additional research is needed to examine the effectiveness of AR in elementary education settings.

Second, previous studies have often focused on learning motivation, engagement, or general academic achievement rather than specifically examining conceptual understanding of science content (Garzón et al., 2020). Conceptual understanding represents a critical educational outcome because it reflects students' ability to construct meaningful scientific knowledge rather than merely memorizing information.

Third, empirical evidence concerning the effectiveness of AR for teaching solar system concepts in elementary schools remains relatively scarce, particularly in developing countries. Differences in educational contexts, technological infrastructure, and learner characteristics necessitate further investigation to determine the applicability of AR-based learning across diverse settings.

The present study seeks to address these gaps by examining the effect of augmented reality media on elementary school students' understanding of solar system concepts. By employing a quasi-experimental design involving experimental and control groups, the study aims to provide empirical evidence regarding the effectiveness of AR-based instruction in promoting conceptual understanding.

The significance of this study extends beyond its contribution to educational theory. From a practical perspective, the findings may provide teachers with evidence-based guidance regarding the use of augmented reality technology in elementary science classrooms. As educational institutions continue to invest in digital technologies, understanding their pedagogical effectiveness becomes increasingly important.

Furthermore, the study contributes to the growing body of literature concerning technology-enhanced learning in science education. By focusing specifically on conceptual understanding of the solar system, the research provides valuable insights into how immersive technologies can facilitate meaningful learning among elementary school students.

The findings may also inform educational policy and curriculum development by highlighting the potential role of augmented reality in supporting science learning outcomes. As schools continue to adopt digital learning innovations, evidence-based recommendations are necessary to ensure that technology integration contributes meaningfully to student learning.

Based on the theoretical foundations, empirical evidence, and identified research gaps, this study aims to examine the effect of augmented reality media on elementary school students' understanding of solar system concepts. Specifically, the study investigates whether students who learn through augmented reality media demonstrate significantly higher conceptual understanding than students who receive conventional instruction. The findings are expected to contribute to educational research, instructional practice, and the advancement of technology-enhanced science education in elementary schools.

METHODS

Research Design

This study employed a quantitative approach with a quasi-experimental research design to investigate the effect of Augmented Reality (AR) media on elementary school students' understanding of the solar system concept. The selection of a quantitative experimental approach was based on the objective of examining causal relationships between the independent variable (Augmented Reality media) and the dependent variable (students' conceptual understanding of the solar system).

The quasi-experimental method was selected because the researcher was unable to randomly assign students to groups due to existing classroom structures established by the school administration. According to Creswell and Creswell (2018), quasi-experimental designs are appropriate in educational settings where random assignment is impractical but comparison between treatment and control groups remains possible.

The study utilized a **Non-Equivalent Control Group Design**, involving an experimental class and a control class. Both groups received pre-tests and post-tests, but only the experimental group received instruction using Augmented Reality media.

The research design can be illustrated as follows.

Experimental Group (SD Negeri Sanding 2)

O1 ———— X ———— O2

Control Group (SD Negeri Sanding 1)

O3 ———— C ———— O4

Figure 1. Research Design

Where:

Symbol Description

O1	Pre-test of experimental group
O2	Post-test of experimental group
O3	Pre-test of control group
O4	Post-test of control group
X	Learning using Augmented Reality media
C	Conventional learning without AR media

The effectiveness of the intervention was determined by comparing changes in conceptual understanding scores between the experimental and control groups after treatment.

Research Setting and Participants

The study was conducted during the second semester of the 2025/2026 academic year. The research took place in two public elementary schools located within the same educational district to ensure relatively similar educational characteristics and curriculum implementation.

The participants consisted of Grade VI students from SD Negeri Sanding 2 and SD Negeri Sanding 1.

Table 1. Research Participants

Group	School	Number of Students
Experimental Class	SD Negeri Sanding 2	30

Group	School	Number of Students
Control Class	SD Negeri Sanding 1	30
Total	-	60

The experimental class received instruction using Augmented Reality media integrated into science learning activities, while the control class learned through conventional instructional approaches involving textbooks, teacher explanations, and static visual materials. Students ranged in age from 11 to 12 years and had previously studied introductory astronomy concepts as part of the national elementary science curriculum.

Research Variables

The study involved two primary variables.

Table 2. Research Variables

Variable Type	Variable
Independent Variable	Augmented Reality Media
Dependent Variable	Understanding of Solar System Concepts

Augmented Reality media served as the instructional treatment implemented during science learning activities. Conceptual understanding of the solar system represented the outcome variable measured through achievement tests.

Treatment Procedures

The intervention was implemented over six consecutive weeks, consisting of twelve instructional sessions.

Students in the experimental class participated in learning activities supported by Augmented Reality applications that visualized three-dimensional models of the solar system. Through mobile devices, students could observe planetary structures, orbital movements, planetary rotation, relative distances, and other astronomical phenomena.

The learning process consisted of several stages. Initially, students received orientation regarding the use of AR technology. Subsequently, they engaged in guided exploration activities using the AR application. Students interacted directly with virtual solar system models, observed scientific phenomena, completed worksheets, participated in discussions, and presented their findings.

The control class received instruction through conventional teaching methods involving lectures, textbook explanations, printed diagrams, and classroom discussions.

The overall research procedure is illustrated below.

Population Identification
↓
Participant Selection
↓
Pre-Test Administration
↓
Experimental Class Control Class
↓ ↓
Augmented Reality Conventional Learning
↓ ↓
Post-Test Administration
↓
Data Analysis

↓
Research Findings

Figure 2. Research Procedure

Research Instrument

The primary instrument used in this study was a Conceptual Understanding Test on Solar System Concepts.
The test was developed based on science curriculum indicators and consisted of multiple-choice and short-answer questions designed to assess students' understanding of:

1. Solar system structure.
2. Characteristics of planets.
3. Planetary motion.
4. Earth's rotation and revolution.
5. Lunar phases.
6. Solar and lunar eclipses.
7. Relationships among celestial bodies.

Table 3. Indicators of Conceptual Understanding

Dimension	Indicator
Interpretation	Explaining scientific concepts
Classification	Identifying characteristics of celestial bodies
Comparison	Distinguishing planetary properties
Explanation	Explaining astronomical phenomena
Application	Applying concepts to solve problems

Instrument Validation

Prior to implementation, the instrument underwent content validation by three experts specializing in science education and educational assessment.
The Content Validity Index (CVI) was employed to determine content validity.
The formula used was:

$$CVI = \frac{\sum X}{N}$$

where:
CVI = Content Validity Index
ΣX = Total expert agreement score
N = Maximum possible score

An instrument was considered valid if the CVI value exceeded 0.80.
Construct validity was examined through Pearson Product Moment correlation analysis.
The correlation coefficient formula was:

$$r_{xy} = \frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{[N\sum X^2 - (\sum X)^2][N\sum Y^2 - (\sum Y)^2]}}$$

Items were considered valid if the calculated correlation coefficient exceeded the critical r-table value.

Reliability Testing

Instrument reliability was evaluated using Cronbach's Alpha.

The formula applied was:

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

where:
α = Reliability coefficient
k = Number of items
Si^2 = Item variance
St^2 = Total variance
A reliability coefficient above 0.70 indicated acceptable reliability.

Data Collection Techniques

Data collection was conducted through several stages.
Initially, pre-tests were administered to both groups to determine baseline conceptual understanding levels. Following the pre-test phase, the experimental class received instruction using Augmented Reality media while the control class participated in conventional learning.
After completion of the intervention period, post-tests were administered to both groups. The resulting scores were recorded and analyzed statistically.

Descriptive Statistical Analysis

Descriptive statistics were used to analyze the mean scores, standard deviations and learning mastery percentages.

Mean Score

The mean score was calculated using:

$$\bar{X} = \frac{\sum X}{N}$$

where:
$\bar{X}$ = Mean score
ΣX = Total score
N = Number of students

Standard Deviation

The standard deviation was calculated using:

$$SD = \sqrt{\frac{\sum (X-\bar{X})^2}{N-1}}$$

The standard deviation was used to determine the degree of score dispersion within each group.

Learning Mastery Percentage

The percentage of learning mastery was calculated using:

$$P = \frac{n}{N} \times 100\%$$

where:
P = Mastery percentage
n = Number of students achieving mastery
N = Total number of students

Score Categorization

Students' conceptual understanding levels were interpreted using the following criteria.

Table 4. Conceptual Understanding Categories

Score Range	Category
86–100	Very High
71–85	High
56–70	Low
≤55	Very Low

These categories were used to interpret both individual and class-average achievement scores.

Inferential Statistical Analysis

Inferential statistical analysis was performed using SPSS version 27.
Before hypothesis testing, prerequisite tests were conducted.

Normality Test

The Shapiro–Wilk test was used because the sample size was fewer than 50 students per group.
The test statistic is expressed as:

$$W = \frac{\left(\sum a_i x_{(i)}\right)^2}{\sum (x_i - \bar{x})^2}$$

Decision criteria:
Sig. > 0.05 → Data are normally distributed.
Sig. ≤ 0.05 → Data are not normally distributed.

Homogeneity Test

Levene's Test was used to examine variance homogeneity.
The test statistic is:

$$F = \frac{(n_i(Z_{i.} - Z_{..})^2}{\left(Z_{ij} - Z_{i.}\right)^2}$$

Decision criteria:
Sig. > 0.05 → Variances are homogeneous.
Sig. ≤ 0.05 → Variances are heterogeneous.

Paired Sample t-Test

The paired sample t-test was used to compare pre-test and post-test scores within the experimental group.
The formula was:

$$t = \frac{\bar{D}}{S_D/\sqrt{n}}$$

where:
$\bar{D}$ = Mean difference score
SD = Standard deviation of differences
n = Number of paired observations

Decision criteria:
Sig. < 0.05 → Significant difference exists.
Sig. ≥ 0.05 → No significant difference exists.

Independent Sample t-Test

The independent sample t-test was employed to compare post-test scores between the experimental and control groups.
The formula was:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{S_p^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where:
$\bar{X}_1$ = Mean of experimental group
$\bar{X}_2$ = Mean of control group
Sp^2 = Pooled variance
n_1 = Experimental sample size
n_2 = Control sample size
Decision criteria:
Sig. < 0.05 → Significant difference exists.
Sig. ≥ 0.05 → No significant difference exists.

Research Ethics

Prior to data collection, permission was obtained from the participating schools. Students and parents were informed regarding the purpose of the study, research procedures, confidentiality of data, and voluntary participation. All collected information was anonymized and used solely for academic research purposes. The study adhered to ethical principles concerning participant welfare, confidentiality, informed consent, and responsible data management throughout the research process.

RESULTS

This section presents the findings obtained from descriptive and inferential statistical analyses conducted to evaluate the effect of Augmented Reality (AR) media on elementary school students' understanding of the solar system concept. The analysis consisted of descriptive statistical tests, prerequisite tests including normality and homogeneity analyses, and hypothesis testing using paired sample t-tests and independent sample t-tests. The findings are presented systematically to provide comprehensive evidence regarding the effectiveness of Augmented Reality media in improving students' conceptual understanding.

Descriptive Statistical Analysis

Descriptive statistical analysis was conducted to examine differences in students' conceptual understanding of the solar system between the experimental and control groups. The analysis focused on mean scores, standard deviations, and learning mastery percentages.

Table 5. Descriptive Statistics of Students' Conceptual Understanding of the Solar System

Group	N	Mean	Standard Deviation	Mastery Percentage (%)	Category
Experimental Class	30	92.37	4.12	94.02	Very High
Control Class	30	69.74	8.56	75.43	Low

Table 5 demonstrates substantial differences in conceptual understanding achievement between students who learned through Augmented Reality media and those who received conventional instruction. The experimental class achieved an average score of 92.37, while the control class obtained an average score of 69.74. This difference of 22.63 points indicates that students exposed to Augmented Reality media demonstrated a considerably higher level of understanding of solar system concepts.

The average score achieved by the experimental class falls within the very high category, whereas the control class remained in the low category. This result suggests that the integration of Augmented Reality media substantially enhanced students' comprehension of astronomy-related concepts compared with conventional learning methods.

An examination of score dispersion further supports these findings. The experimental class recorded a standard deviation of 4.12, while the control class showed a substantially higher standard deviation of 8.56. A smaller standard deviation indicates that student achievement was distributed more uniformly around the mean score.

The relatively low standard deviation in the experimental group suggests that most students benefited consistently from the intervention. In contrast, the larger standard deviation in the control class indicates greater variability in student achievement levels.

These findings imply that Augmented Reality media not only improved average conceptual understanding but also contributed to more equitable learning outcomes among students.

The mastery percentage data provide additional evidence regarding the effectiveness of the intervention. The experimental class achieved a mastery percentage of 94.02%, indicating that nearly all students successfully met the established learning criteria. Meanwhile, the control class achieved a mastery percentage of only 75.43%. Although this percentage indicates that some students achieved satisfactory learning outcomes, it remains substantially lower than that observed in the experimental group.

The difference in mastery percentages of approximately 18.59% highlights the superior effectiveness of Augmented Reality media in facilitating students' achievement of learning objectives. The high mastery rate observed in the experimental class suggests that the instructional intervention successfully supported a broad range of learners, including students who may have initially struggled with abstract scientific concepts. The findings indicate that the visual and interactive features of Augmented Reality helped students develop a deeper understanding of solar system structures, planetary characteristics, and astronomical relationships.

The higher average score achieved by the experimental group suggests that students developed stronger conceptual representations of scientific phenomena through AR-assisted learning. The reduced variability among students in the experimental class indicates that AR media may help minimize learning gaps by providing concrete visualizations that support understanding for learners with different ability levels.

Furthermore, the mastery percentage results indicate that Augmented Reality media facilitated meaningful learning experiences capable of supporting achievement across the majority of participants.

Collectively, the descriptive findings provide strong preliminary evidence that AR-based instruction positively influenced students' conceptual understanding of the solar system.

The observed differences between groups warrant further examination through inferential statistical analyses to determine whether these differences are statistically significant. Consequently, prerequisite testing was conducted prior to hypothesis testing.

Normality Test

The Shapiro–Wilk test was employed to examine whether the data were normally distributed.

Table 6. Results of Normality Test

Data	Sig. Value	Alpha	Decision
Experimental Class	0.176	0.05	Normal
Control Class	0.148	0.05	Normal

The results presented in Table 6 indicate that all significance values exceeded the alpha level of 0.05. Therefore, the data were normally distributed. The fulfillment of the normality assumption indicates that the distribution of conceptual understanding scores approximated a normal curve. Because the normality requirement was satisfied, parametric statistical techniques could be employed for hypothesis testing. The normal distribution of data strengthens the validity of subsequent inferential analyses.

Homogeneity Test

Variance homogeneity was examined using Levene's Test.

Table 7. Results of Homogeneity Test

Variable	Sig. Value	Alpha	Decision
Conceptual Understanding	0.283	0.05	Homogeneous

Table 7 shows that the significance value exceeded 0.05. Therefore, the variances of the two groups can be considered homogeneous. This finding indicates that the experimental and control groups originated from populations possessing similar variance structures. The fulfillment of the homogeneity assumption further supports the application of parametric hypothesis testing procedures. Because both normality and homogeneity assumptions were satisfied, the independent sample t-test and paired sample t-test could be conducted appropriately.

Paired Sample t-Test

The paired sample t-test was conducted to examine differences in conceptual understanding before and after treatment within the experimental group.

Table 8. Results of Paired Sample t-Test

Comparison	Mean Difference	t-value	Sig. (2-tailed)	Decision
Pre-test vs Post-test (Experimental)	30.45	19.742	0.000	Significant

The paired sample t-test yielded a significance value of 0.000, which is lower than 0.05. This result indicates a statistically significant increase in students' conceptual understanding after participation in AR-assisted learning. The large mean difference further demonstrates the practical significance of the intervention. These findings confirm that Augmented Reality media contributed substantially to students' conceptual development.

Independent Sample t-Test

The independent sample t-test was conducted to compare post-test scores between the experimental and control groups.

Table 9. Results of Independent Sample t-Test

Variable	Mean Experimental	Mean Control	t-value	Sig. (2-tailed)	Decision
Conceptual Understanding Post-test	92.37	69.74	15.863	0.000	Significant

The independent sample t-test produced a significance value of 0.000, which is lower than the predetermined alpha level of 0.05. This finding indicates a statistically significant difference between students who learned using Augmented Reality media and those who received conventional instruction.

The substantially higher mean score of the experimental group confirms the effectiveness of AR-based learning in promoting conceptual understanding.
The inferential findings support the research hypothesis that Augmented Reality media significantly enhances elementary school students' understanding of solar system concepts.

Taken together, the descriptive and inferential analyses provide strong empirical evidence supporting the effectiveness of the intervention.

The consistency between statistical significance and practical improvements strengthens confidence in the study findings. The results indicate that Augmented Reality media constitutes a promising instructional innovation for elementary science education.

DISCUSSION

The findings of this study demonstrate that Augmented Reality media significantly improved elementary school students' understanding of solar system concepts. Students who participated in AR-assisted learning achieved substantially higher conceptual understanding scores than students who received conventional instruction. These findings provide empirical support for the growing body of literature emphasizing the educational value of immersive technologies in science learning environments.

One of the most notable findings concerns the considerable difference in average achievement between the experimental and control groups. The experimental group achieved a mean score of 92.37, whereas the control group obtained only 69.74. This substantial difference suggests that Augmented Reality provided learning experiences capable of facilitating deeper conceptual understanding than traditional instructional approaches.

The superiority of Augmented Reality can be explained through the visualization capabilities embedded within the technology. The solar system is characterized by highly abstract concepts involving celestial objects, orbital movements, and spatial relationships that cannot be directly observed by students. AR technology enables learners to visualize these phenomena in three-dimensional formats, thereby making abstract concepts more concrete and comprehensible.

This finding is consistent with the Cognitive Theory of Multimedia Learning proposed by Mayer (2021), which argues that meaningful learning occurs when learners actively process information through both verbal and visual channels. Augmented Reality enriches the learning process by combining textual explanations with dynamic visual representations, thereby supporting more effective cognitive processing. The significant improvement observed in the experimental class also aligns with Dual Coding Theory (Paivio, 2014). According to this theory, information presented through multiple representational systems is more likely to be understood and retained. Through AR applications, students simultaneously received verbal explanations and visual representations of astronomical phenomena, enhancing conceptual encoding and retrieval.

Another important finding concerns the lower standard deviation observed in the experimental class. The smaller variability of scores suggests that the benefits of Augmented Reality were experienced by most students rather than only by high-achieving learners. This result indicates that AR media may contribute to more equitable learning outcomes. The reduction in score dispersion supports previous research by Garzón et al. (2020), who reported that AR-based learning environments can improve accessibility to complex scientific concepts for diverse learners. Interactive visualizations reduce cognitive barriers and support understanding among students with varying levels of prior knowledge.

The high mastery percentage achieved by the experimental group further strengthens evidence regarding the effectiveness of AR-based instruction. More than ninety-four percent of students successfully achieved the expected learning standards after participating in the intervention. This finding suggests that Augmented Reality media facilitated not only conceptual improvement but also successful attainment of curriculum objectives. Such outcomes are particularly important in elementary science education, where conceptual foundations influence future learning experiences.

The effectiveness of AR-based learning can also be explained through constructivist learning theory. Constructivism emphasizes that knowledge is actively constructed through interactions with the environment (Piaget, 1972). Augmented Reality creates opportunities for active exploration, observation, and manipulation of virtual objects, enabling students to construct knowledge through direct experience. The interactive nature of AR applications encourages students to engage actively with learning content. Rather than passively receiving information, learners become participants in the learning process by examining planetary movements, observing celestial relationships, and exploring scientific phenomena independently.

These findings correspond with the work of Akçayır and Akçayır (2017), whose meta-analysis concluded that Augmented Reality positively influences academic achievement, conceptual understanding, and learner engagement across educational contexts. The present findings also support research conducted by Ibáñez and Delgado-Kloos (2018), who found that AR technologies are particularly effective for science education because they provide realistic representations of otherwise inaccessible phenomena. The solar system represents an ideal application area for AR technology because direct observation of planetary movements and astronomical structures is generally impossible within conventional classroom settings. Through AR visualizations, students can explore these phenomena in ways that closely approximate authentic observation.

The observed improvements may also be associated with increased learner motivation. Interactive and visually appealing learning environments often stimulate curiosity and sustain attention, which contribute positively to cognitive engagement and learning outcomes. Previous studies have shown that motivation serves as an important mediator between instructional technology and academic achievement (Radianti et al., 2020). Students who are more motivated tend to invest greater cognitive effort in learning tasks.

The findings additionally highlight the importance of technological innovation in elementary science education. Traditional instructional approaches often rely on static images and verbal explanations that may be insufficient for explaining complex scientific concepts. AR provides a more dynamic and immersive alternative. Another notable implication concerns scientific literacy development. Conceptual understanding constitutes a fundamental component of scientific literacy because it enables students to explain, interpret, and apply scientific knowledge appropriately. Therefore, improving conceptual understanding through AR may contribute indirectly to broader science literacy goals. The findings are also relevant to current educational reforms emphasizing digital transformation and technology integration. Educational systems worldwide increasingly encourage the use of digital technologies to support meaningful learning experiences and twenty-first-century competencies (OECD, 2023). Within the Indonesian educational context, the results provide evidence supporting the implementation of innovative learning media aligned with the objectives of the Merdeka Curriculum. The curriculum emphasizes active learning, technological integration, and conceptual understanding, all of which are facilitated through AR-based instruction.

The significant results observed in this study suggest that AR media can serve as a practical instructional solution for addressing persistent difficulties associated with astronomy learning in elementary schools. Teachers may utilize AR applications to supplement existing instructional materials and provide richer learning experiences for students. Such integration may be particularly valuable when teaching concepts involving spatial relationships, movement, and abstract scientific processes. School administrators may also consider investing in AR infrastructure and teacher training programs to support broader implementation of immersive learning technologies. From a curriculum perspective, the findings support the incorporation of digital visualization tools into science education frameworks. Such tools can facilitate conceptual development while simultaneously enhancing student engagement.

Despite the positive findings, several limitations should be acknowledged. The study involved participants from only two elementary schools, which may limit the generalizability of the results to other educational contexts. Additionally, the intervention period was relatively short. Future research involving longitudinal designs could provide greater insight into the long-term effects of AR-based learning on conceptual retention and transfer. Future studies may also investigate the influence of AR technology on other educational outcomes, including scientific reasoning, problem-solving ability, inquiry skills, motivation, and academic achievement.

The findings provide strong evidence that Augmented Reality media represents an effective instructional tool for improving elementary school students' understanding of solar system concepts. By transforming abstract scientific phenomena into interactive and visually accessible experiences, AR facilitates meaningful conceptual learning and offers significant potential for enhancing science education in elementary schools.

CONCLUSION

This study concludes that the use of Augmented Reality media has a positive and statistically significant effect on elementary school students' understanding of solar system concepts. Students who learned through Augmented Reality achieved higher conceptual understanding scores, higher learning mastery percentages, and more consistent learning outcomes than students who participated in conventional instruction. These findings indicate that the integration of interactive three-dimensional visualizations can support students in understanding abstract astronomical concepts that are often difficult to comprehend through traditional learning approaches. Within the context of this study, Augmented Reality media can be considered a promising instructional alternative for supporting science learning in elementary schools. Nevertheless, the findings should be interpreted within the limitations of the study setting and sample size. Future research involving larger participant groups, diverse educational contexts, and longer intervention periods is recommended to further explore the effectiveness and sustainability of Augmented Reality-based learning in elementary science education.

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