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Exploring the Effectiveness of PjBL in Enhancing Students' Understanding of Astronomy Concepts Using Universe Sandbox

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Abstract. Challenges in elementary education frequently arise from the continued use of conventional and monotonous teaching methods, which often lead to low student engagement and difficulty in grasping abstract concepts such as astronomy. These issues are further compounded by the limited availability of digital learning tools and insufficient teacher training. The gap between the expected implementation of interactive learning and actual classroom practices highlights the urgent need for innovative approaches. One such approach is PjBL integrated with interactive media to improve students' conceptual understanding. This study aims to (1) analyze students' conceptual understanding of astronomy before and after instructional intervention, and (2) measure the extent of improvement achieved through the implementation of PjBL supported by Universe Sandbox media. Employing a quasi-experimental design (one-group pretest-posttest) involving 32 sixth-grade students at SDN 7 Gondosari, data were collected using tests, observations, interviews, and documentation. The data were analyzed through normality testing, paired sample t-tests, and N-Gain calculations. The results indicated a statistically significant difference between pretest and posttest scores, with the paired sample t-test yielding a Sig. (2-tailed) value of 0.000 (<0.05), suggesting a substantial increase in conceptual understanding. Additionally, the N-Gain analysis produced an average score of 0.7486, categorized as moderate to high improvement. These findings confirm that the PjBL model, when supported by Universe Sandbox media, is effective in enhancing students' comprehension of astronomical concepts.

Keywords: Astronomy; Concept Understanding; Interactive Learning; PjBL; Universe Sandbox

1. Introduction

The Merdeka Curriculum was developed in response to various challenges within Indonesia's education system, particularly in enhancing the quality of learning to meet contemporary demands. This curriculum offers teachers flexibility in designing student-centered learning through project-based approaches facilitating active student participation (Wardani et al., 2023). Emphasizing exploration, collaboration, and innovation, the Merdeka Curriculum aims to create learning experiences that are both engaging and meaningful for students.

Education plays a crucial role in establishing students' foundational understanding at the elementary level. This stage is students' initial introduction to fundamental concepts across various disciplines (Yasykur et al., 2023). When implemented effectively, elementary education can stimulate curiosity, develop logical thinking patterns, and cultivate early problem-solving skills. Subjects such as science and technology should be delivered through engaging and relevant methods to facilitate comprehension and practical application (Awad, 2023). However, current teaching practices often remain conventional and inadequately integrated with technology. Many Indonesian schools have not optimized digital learning media, resulting in text-heavy and passive instruction (Hayati & Syaikhu, 2020). This leads to monotonous learning experiences, where teachers predominantly rely on lecture-based methods, leaving students as passive recipients rather than active participants in conceptual exploration (Khamdun et al., 2021).

Astronomy education presents particular challenges in this context. The digital era demands that students develop critical, collaborative, and creative thinking skills (Pulingkareng et al., 2021). Consequently, innovative teaching approaches that capture student interest and enhance conceptual understanding are essential. Astronomical concepts such as Earth's rotation, revolution, and solar system dynamics have significant potential to stimulate student curiosity and foster logical, systematic thinking (Clemente et al., 2022). However, these concepts are often perceived as difficult due to limitations in instructional media. Text-based or lecture-driven delivery methods make it challenging for students to grasp these abstract concepts concretely, highlighting the need for more interactive, experiential approaches to astronomy education. Conceptual understanding is a key indicator of learning success, enabling students to connect new knowledge with prior experiences and facilitating mastery of more complex material in the future (Ardianti et al., 2023).

Elementary education should provide enjoyable, interactive, and meaningful learning experiences, particularly for complex subjects like astronomy (Akimkhanova et al., 2023). Innovative approaches are necessary to help students connect theory with practice. Teachers should be facilitators who encourage exploration, collaboration, and critical thinking while providing supportive resources such as interactive learning media and digital technologies. Although the Merdeka Curriculum offers the flexibility to achieve ideal learning conditions, actual classroom practices in elementary schools often remain conventional and monotonous.

Project-Based Learning (PjBL) presents a viable solution for enhancing student understanding, particularly for abstract concepts. This approach enables active, collaborative learning through relevant projects, helping students connect theoretical knowledge with practical applications. PjBL increases student engagement and helps develop essential 21st-century skills, including critical thinking, creativity, communication, and collaboration (Rahmawati et al., 2021). However, PjBL implementation faces challenges, including extended time requirements and dependence on teachers' competency in project design and guidance. Infrastructure and resource limitations, particularly in rural areas, constrain effective implementation. Integrating interactive learning media such as Universe Sandbox is highly recommended to address these challenges. This digital platform enables students to visualize abstract concepts through interactive simulations of astronomical phenomena, including planetary rotation, eclipses, and solar system dynamics (Saleh et al., 2020). Combining PjBL and Universe Sandbox can create practical and innovative learning experiences, particularly in astronomy education.

1.1. Problem Statement

Ideally, astronomy instruction in Grade 6 at SDN 7 Gondosari should foster a deep understanding and stimulate students' enthusiasm for science. However, observations and interviews revealed a significant gap between this ideal expectation and actual classroom conditions. While many students demonstrate interest in astronomy topics, they struggle to comprehend abstract concepts due to teaching methods that rely heavily on textbooks without adequate visual aids. The school's limited resources present a significant barrier to creating interactive and engaging learning experiences.

The homeroom teacher acknowledged that monotonous teaching methods hinder students from thoroughly understanding the material. This aligns with student feedback expressing frustration over the lack of visual media such as images, videos, or simulations to aid their comprehension. Meanwhile, teachers face challenges developing innovative teaching models due to insufficient training and reference materials. This condition is supported by research from Surur (2023), which emphasizes that students learn more effectively when information is presented in both verbal and visual formats, especially for abstract or complex topics. Similarly, Hunter (2023) highlight that traditional teaching methods often fail to activate students' prior knowledge and limit opportunities for meaningful learning, particularly in science education. The impact of these issues is reflected in the average score of the Learning Objective Achievement Criteria (LOAC), which reached only 69, still below the school's target of 80. This situation highlights the need for more creative teaching approaches, the integration of visual media, and teacher training to enhance the quality of astronomy instruction. By addressing these gaps, students' comprehension can improve, making science learning more engaging and meaningful.

1.2. Related Research

A comprehensive review of existing literature reveals consistent evidence regarding the efficacy of PjBL in enhancing student learning outcomes. Husna (2022)demonstrated the effectiveness of this model in science education at elementary school, while Liao (2021) reported comparable results in the context of elementary-level mathematics concept acquisition. These studies share fundamental similarities with current research in utilizing PjBL methodology and focusing on improving students' conceptual understanding. However, a significant divergence emerges in the employment of instructional media, with earlier studies failing to optimize visual learning tools.

The investigations conducted by Pratiwi (2023) and Sevani (2023) provide broader insights into PjBL implementation across different educational levels. Yang's (2024) research involving junior high school students established that while PjBL effectively enhanced conceptual comprehension, inadequate instructional media posed substantial obstacles in delivering complex astronomical content. Similarly, Akimkhanova (2023) study, which incorporated traditional games as learning tools, proved insufficient for visualizing abstract astronomical principles. These studies collectively identify a critical gap in the need for more interactive instructional media aligned with students' cognitive development levels.

This current study introduces three principal innovations. First, it employs Universe Sandbox, a digital platform that delivers dynamic and interactive visual simulations of astronomical concepts. Second, it explicitly targets elementary students, who require more concrete pedagogical approaches than their junior high counterparts. Third, it emphasizes profound astronomical understanding, contrasting with Agustina (2022) broader focus on general scientific literacy.

The novelty of this research lies in its unique integration of the PjBL model with Universe Sandbox a specific and highly visual simulation tool in the context of elementary astronomy education, which has not been explored in previous studies. While past research has examined PjBL or visual media independently, this study combines both components to address the dual challenges of abstract concept delivery and student engagement in science learning.

The comparative analysis reveals several important implications, although the effectiveness of PjBL has been empirically validated across various contexts, its integration with appropriate instructional media proves to be a critical success factor, especially for teaching abstract subjects such as astronomy. Consequently, this study makes a meaningful contribution to the advancement of elementary science pedagogy by addressing challenges related to instructional media and teaching methodologies identified in previous research.

1.3. Research Objective

The study aimed to (1) analyze Grade 6 students' conceptual understanding of astronomy before and after implementing PjBL with Universe Sandbox media, and (2) measure the learning improvements from this approach. By addressing limitations in Indonesia's Merdeka Curriculum where traditional methods failed to teach abstract concepts the research evaluated how PjBL combined with interactive simulations enhanced comprehension of topics such as planetary motion. The expected outcomes included quantitative learning gains, qualitative insights into the role of digital visualization, and practical strategies for implementing technology-aided PjBL in schools with limited resources.

2. Theoretical Framework

This study encompasses a theoretical framework comprising three key components: the PjBL Model, Natural and Social Sciences (NSS) in Elementary School, Process Skill, Conceptual Understanding, and Universe Sandbox Media.

2.1. PjBL Model

A learning model represents a systematic instructional framework specifically designed to facilitate students' development of a comprehensive understanding of the subject matter. This pedagogical approach encompasses well-defined procedures, structured activities, and fundamental principles that guide educators in effectively managing the learning process (Hudha et al., 2023). Suryanti (2024) further elaborate that a learning model constitutes an integrated system synthesizing various educational components, including content materials, instructional methods, media tools, and assessment techniques, to create optimal learning experiences. These models serve dual purposes: providing practical implementation guidelines for teachers while simultaneously addressing students' psychological and pedagogical needs to maximize learning outcomes. The ultimate objective is to tailor instructional approaches to students' specific requirements, enhancing overall educational effectiveness.

PjBL represents an innovative instructional methodology that centers on authentic project completion as the primary mechanism for achieving learning objectives. Within this framework, students engage in comprehensive tasks involving the planning, executing, and finalizing of projects directly relevant to the curriculum content (Sholahuddin et al., 2023). The PjBL approach facilitates experiential learning by enabling students to integrate cross-disciplinary knowledge while developing essential 21st-century skills, including critical thinking, creative problem-solving, and collaborative abilities (Ardithayasa et al., 2022). As Rosidin (2023) emphasizes, PjBL fundamentally emphasizes challenging, project-driven learning experiences that encourage students to work cooperatively, investigate solutions, and apply acquired knowledge in real-world contexts. This characteristic distinguishes PjBL from traditional teacher-centered instructional models by transforming students from passive information recipients into active participants who demonstrate improved conceptual understanding and content mastery through hands-on engagement.

The PjBL model follows a structured six-phase implementation sequence identified by Farcis (2022). The initial phase involves formulating essential questions that establish the project's fundamental inquiry base and define its parameters. Subsequently, student’s progress to designing comprehensive project plans that outline specific implementation strategies. The third phase requires developing detailed timelines for project execution, followed by the crucial monitoring stage, where teachers facilitate and supervise project progress. The fifth phase focuses on outcome assessment through formal reporting and presentation of results. Finally, the model concludes with a comprehensive experience evaluation involving reflective analysis of the learning process and outcomes. This systematic yet flexible approach ensures methodical implementation while accommodating diverse learning contexts and objectives, particularly in complex subject areas where profound conceptual understanding benefits from sustained, project-based engagement.

2.2. Natural and Social Sciences (NSS) in Elementary School

NSS constitutes an interdisciplinary field that examines living organisms, inanimate objects in the universe, and their interactions while also investigating human life as individuals and as social beings interacting with their environment. Generally defined as an organized body of knowledge systematically arranged through logical consideration of cause-and-effect relationships (Komariah et al., 2023), NSS in elementary education integrates NSS to provide foundational knowledge about the natural world and human relationships with both environment and society (Fradina et al., 2022). This subject engages students in understanding various natural and social phenomena while developing critical, analytical, and creative thinking skills. NSS offers students opportunities to explore the world through contextual approaches that connect academic knowledge with relevant life experiences.

The primary objectives of NSS in elementary education involve introducing fundamental concepts from both scientific domains. In natural sciences, students investigate phenomena such as plants, animals, weather patterns, and celestial bodies. The social science component examines community life, culture, history, and geography to help students understand human interactions and relationships with sociocultural environments (Saputro et al., 2024). NSS instruction emphasizes holistic approaches where both disciplines are taught integrative. Teachers deliver theoretical knowledge and facilitate discussions, experiments, and observations of natural and social phenomena Hidayah (2023), establishing foundations for deeper understanding at subsequent educational levels.

2.3. Process Skill

Process skills refer to the systematic cognitive and operational abilities employed in discovering, developing, and applying scientific concepts. These essential skills encompass observation, classification, measurement, inference, and effective communication of findings. Within the NSS curriculum, process skills enable students to comprehend cause-and-effect relationships in natural and social phenomena, thereby facilitating the construction of independent understanding through hands-on exploration and experimentation (Hardiansyah et al., 2022). These multidimensional skills integrate cognitive, psychomotor, and affective domains, supporting students in environmental exploration and information acquisition. For instance, when studying ecosystem concepts, students extend beyond theoretical knowledge by conducting field observations to examine interactions between organisms and their environment (Akbariah et al., 2023).

In NSS education, process skills constitute a fundamental, integrated skillset that empowers students to conduct independent scientific investigations. This comprehensive approach involves sequential stages, including hypothesis formulation, experimental design, data collection, and evidence-based conclusion drawing (Perdana et al., 2022). Through process skill development, students transcend rote memorization to cultivate logical, systematic, and innovative thinking capacities applicable to real-world problem-solving contexts.

Scientific inquiry skills are intrinsically linked to students' understanding of scientific content, providing structural framework and methodological processes for knowledge acquisition. These skills encompass (1) observation, (2) questioning and prediction, (3) investigation planning and implementation, (4) data processing, (5) information analysis, (6) evaluation and reflection, and (7) results communication. Rather than representing a rigid linear sequence, process skills form a dynamic, adaptable cycle that can be modified according to students' developmental progress and capabilities (BSKAP, 2024). Key measurable indicators of process skills include observing, classifying, communicating, measuring, predicting, and drawing valid conclusions.

2.4. Concept Understanding

Conceptual understanding represents a fundamental cognitive ability crucial to the learning process. According to Arnellis (2023), it involves comprehending the meaning of subject matter through activities such as translating, interpreting, and classifying relevant information. Muali (2020) expands this definition to include students' capacity to recognize interrelationships among conceptual elements and apply them across diverse contexts. Lukitasari (2020) further emphasizes that conceptual understanding requires individuals to connect new information with prior knowledge to solve problems effectively. Tampubolon (2023) conceptualizes it as a cognitive process involving assimilation and accommodation to form mental structures that organize new information. Rahmadhani (2024) defines it as the ability to identify core characteristics of ideas for practical task completion.

Conceptually, conceptual understanding denotes the capacity to thoroughly comprehend and integrate ideas, procedures, or mathematical facts. The depth of such understanding depends on the degree of interconnectedness among these elements and the strength of their conceptual network (Arnellis et al., 2023). Synthesizing these perspectives, conceptual understanding emerges as integrating new knowledge with prior experiences to effectively comprehend, organize, and apply ideas across various situations.

Mayasari (2021) identifies three key indicators of conceptual understanding. First, the ability to provide examples and non-examples of a concept is demonstrated when students cite concrete instances of integer applications in daily life situations. Second, the capacity to explain definitions using one's own words while capturing essential characteristics is observable when students restate integer concepts in their language. Third, competence in applying concepts to problem-solving is measurable through students' performance in addressing challenges. These indicators collectively provide a framework for assessing the depth and quality of students' conceptual mastery.

2.5. Universe Sandbox Media

Universe Sandbox is an instructional medium designed to enhance students' understanding of astronomical concepts through interactive virtual exploration. This digital platform enables learners to investigate and engage with astronomical objects and phenomena, including planets, stars, and galaxies, in an open-ended, sandbox-style environment. Utilizing advanced three-dimensional simulations, the medium allows students to study celestial mechanics, comprehend astronomical theories, and conduct direct experiments and observations of phenomena such as planetary motion, seasonal changes, and eclipses. By providing dynamic visualizations and hands-on manipulation of cosmic systems, Universe Sandbox facilitates experiential learning that bridges abstract concepts with tangible representations, thereby fostering deeper conceptual understanding in astronomy education. This tool's interactive nature enhances student engagement and supports the development of scientific inquiry skills through authentic, inquiry-based exploration of the universe. Below is Figure 1, illustrating the Universe Sandbox media:

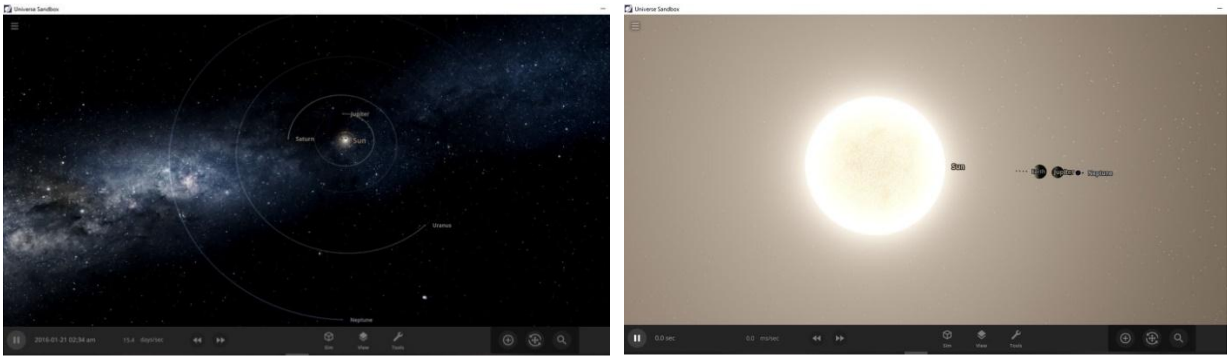

Figure 1. Universe Sandbox Media

3. Method

3.1. Research Design

This study employs a quantitative approach, utilizing numerical data to describe research findings. Specifically, it adopts a quasi-experimental design to examine the direct effect between variables (Franklin, 2022). The research method used was pre-experimental research using a one-group pretest-posttest design, with the research objects being the PjBL model incorporating Universe Sandbox media (variable X) and students' conceptual understanding abilities (variable Y). The research subjects consist of sixth-grade students at SDN 7 Gondosari. Within this quasi-experimental framework, the study utilizes a one-group pretest-posttest Design. This model enables the researcher to measure changes or effects within the same group before and after the intervention, which involves implementing the PjBL approach supported by Universe Sandbox media.

3.2. Respondent

The population in this study consists of all sixth-grade students at the school, totaling 32 students. The selection of the sixth-grade class as the sample was based on the results of the Mid-Semester Assessment (MSA) for the subjects of NSS, which indicated that students' conceptual understanding consistently remained at a low level. This study employed a non-probability sampling method using saturated sampling techniques, where the entire population was included as the sample due to its relatively small size (fewer than 100 participants). Therefore, all 32 students were taken as the sample and designated as the experimental group. This group was subsequently provided with treatment in the form of PjBL enhanced by the Universe Sandbox media to improve their conceptual understanding.

Table 1. Sample Respondents

Female	Male	Total
14	18	32

Table 1 summarizes the demographic distribution of the sample respondents, classified by gender. The data reveals that there are 14 female respondents and 18 male respondents, culminating in a total of 32 participants. This gender composition is significant for understanding the diversity within the sample, which may influence the study's findings and interpretations. Such demographic details are crucial for contextualizing the results and ensuring that any conclusions drawn are reflective of the sample's characteristics.

3.3. Data Collection

The data collection methods in this study aim to obtain test results that accurately reflect the conceptual understanding abilities of sixth-grade students. The techniques employed include pretest and posttest administrations and non-test methods such as observation, interviews, and documentation. The pretest is administered before the intervention to measure students' baseline understanding, while the posttest is conducted following the treatment to evaluate changes in their conceptual mastery. These assessments measure students' conceptual understanding based on predetermined evaluation criteria.

Interviews are a primary non-test technique for gathering objective information throughout the research process. This verbal interaction involves structured questioning, with responses recorded immediately after each session to ensure data accuracy. The study used an interview guide to gather valuable insights from participants. This method enables researchers to systematically collect primary data while maintaining alignment with the established research framework. Furthermore, observations are carried out using standardized observation sheets designed to enhance data validity and minimize potential bias, with entries completed in real time during each observation session.

Documentation techniques are implemented to record and preserve tangible evidence of all research activities systematically. As supplementary research data, documentation provides verifiable records of relevant activities, thereby supporting the overall research process. In this study, documentation methods assist researchers in compiling necessary data while ensuring comprehensive recording of all research-related information. This triangulation of data collection methods - combining tests, interviews, observations, and documentation - strengthens the study's validity and reliability by providing multiple perspectives on the intervention's effectiveness.

3.4. Data Analysis

The data analysis in this study follows a systematic methodological procedure comprising several distinct stages. The initial phase involves sample validity testing through prerequisite analyses, which is the foundation for subsequent hypothesis testing. The Shapiro-Wilk normality test is employed to verify whether the data distribution conforms to a regular pattern, constituting a fundamental requirement for further parametric statistical analysis. Upon confirming the normality assumption, the study proceeds to hypothesis testing utilizing two primary analytical techniques.

The first technique is the Paired Sample T-Test, implemented to examine the significance of differences between pretest and posttest scores within the One Group Pretest-Posttest design. This test is selected based on the paired nature of the data collected from the same subjects before and after the intervention, with the essential precondition that the data must be normally distributed. The second technique involves N-Gain analysis, which quantitatively measures the magnitude of improvement in students' conceptual understanding. This analysis compares the difference between pretest and posttest scores against the maximum possible score, processed using SPSS 26 software.

The combination of these analytical approaches enables researchers to identify significant differences before and after the intervention and quantify the extent of improvement at both individual and class levels. This comprehensive analytical procedure is designed to provide a complete picture of the effectiveness of the PjBL model supported by Universe Sandbox media in enhancing sixth-grade students' astronomical conceptual understanding at SDN 7 Gondosari. The methodological rigor ensures robust findings while maintaining statistical validity throughout the analytical process.

3.5. Validity

This study ensures data validity through a rigorous validation process, validity reflects the degree to which research data accurately represents the studied phenomenon. Specifically, the study employs content validity (Afriana et al., 2022). which assesses the alignment between research instruments and the targeted measurement domain. Expert judgment was conducted on all research instruments to establish content validity. The validation process involved competent education specialists in their respective fields: concept understanding tests were validated by two pedagogy experts. Universe Sandbox media was evaluated by instructional media specialists, science education experts, and elementary education practitioners who assessed teaching modules. This comprehensive validation process confirms that all instruments - including evaluation tests, learning media, and teaching modules - meet established content validity standards before field implementation, thereby ensuring academically accountable research outcomes. This validation approach, as outlined in Tables 2 and 3, highlights the careful revisions made to the research instrument based on expert feedback, ensuring that it effectively measures students' conceptual understanding in the context of PjBL utilizing the Universe Sandbox medium.

Table 2. Expert Validation Result

No.	Instrument	Expert Reviewer	Skor	Criteria	Suggestions for Improvement
1.	Test	Siti Masfuah S. Pd, M. Pd	33	B (Good)	Review theoretical framework, adjust question difficulty levels, improve diction and scoring rubric
2.	Test	Fera Christiana Natalia, S. Pd. SD	75	A (Excellent)	Ready for use
3.	Media	Fatikhatun Najikhah, S. Pd, M. Pd	26	A (Excellent)	Develop user manual for the media
4.	Media	Fera Christiana Natalia, S. Pd. SD	83	A (Excellent)	Ready for use
5.	Teaching Module	Dr. Yuni Ratnasari, S. Si, M. Pd	63	A (Excellent)	Improve grammatical structure and clearly present project outcomes
6.	Teaching Module	Fera Christiana Natalia, S. Pd. SD	38	A (Excellent)	Ready for use

Table 2 presents the expert validation results for various research instruments. The first Test, reviewed by Siti Masfuah S. Pd, M. Pd, received a score of 33 (B, Good), with suggestions to review the theoretical framework and adjust question difficulty levels. Fera Christiana Natalia, S. Pd. SD evaluated another Test, scoring 75 (A, Excellent), indicating it is ready for use. In the Media category, Fatikhatun Najikhah, S. Pd, M. Pd gave a score of 26 (A, Excellent) and recommended developing a user manual, while Fera Christiana Natalia scored another Media at 83 (A, Excellent), confirming its readiness. The Teaching Module assessed by Dr. Yuni Ratnasari, S. Si, M. Pd scored 63 (A, Excellent), with recommendations for improving grammatical structure. A final Teaching Module, reviewed by Fera Christiana Natalia, scored 38 (A, Excellent), also deemed ready for use. This table encapsulates the experts' feedback aimed at enhancing the quality of the research instruments.

Revisions of all research instruments. These revisions were meticulously executed, incorporating all notes and improvement recommendations provided by the validators. After refinement, the revised instruments were resubmitted to experts for revalidation. This second validation in Table 3 phase aimed to verify that all improvements had been adequately implemented and that the research instruments now fully met established validity criteria. This iterative process guarantees the quality and validity of research instruments before data collection, ensuring methodological rigor throughout the study. The validation outcomes demonstrate that all instruments achieved either "Good" or "Excellent" ratings, with specific improvement areas addressed through expert recommendations, ultimately yielding research tools that meet rigorous educational research standards.

Table 3. Final Expert Validation Results

No.	Instrument	Expert Reviewer	Skor	Criteria	Suggestions for Improvement
1.	Test	Siti Masfuah S. Pd, M. Pd	33	B (Good)	Review theoretical framework, adjust question difficulty levels, improve diction and scoring rubric
2.	Test	Fera Christiana Natalia, S. Pd. SD	75	A (Excellent)	Ready for use
3.	Media	Fatikhatun Najikhah, S. Pd, M. Pd	26	A (Excellent)	Develop user manual for the media
4.	Media	Fera Christiana Natalia, S. Pd. SD	38	A (Excellent)	Ready for use
5.	Teaching Module	Dr. Yuni Ratnasari, S. Si, M. Pd	63	A (Excellent)	Improve grammatical structure and clearly present project outcomes
6.	Teaching Module	Fera Christiana Natalia, S. Pd. SD	42	A (Excellent)	Ready for use

Table 3 presents the final expert validation results for various research instruments. The first Test, evaluated by Siti Masfuah S. Pd, M. Pd, received a score of 33 (B, Good) with suggestions to review the theoretical framework and adjust question difficulty levels. In contrast, Fera Christiana Natalia, S. Pd. SD scored another Test at 75 (A, Excellent), indicating it is ready for use. For the Media, Fatikhatun Najikhah, S. Pd, M. Pd assigned a score of 26 (A, Excellent) and recommended developing a user manual, while Fera Christiana Natalia scored another Media at 38 (A, Excellent), also confirming its readiness. The Teaching Module assessed by Dr. Yuni Ratnasari, S. Si, M. Pd received a score of 63 (A, Excellent), with recommendations for improving grammatical structure and presentation of project outcomes. Finally, a second Teaching Module reviewed by Fera Christiana Natalia scored 42 (A, Excellent), indicating it is ready for use. This table encapsulates the experts' feedback aimed at refining the research instruments.

Through this validation approach, the research instruments are expected to accurately measure students' conceptual understanding within implementing PjBL utilizing Universe Sandbox media.

4. Findings

This study aimed to (1) examine students' conceptual understanding of astronomy before and after instruction, and (2) measure the improvement in understanding through the PjBL model assisted by Universe Sandbox. Based on data collected from tests, observations, and documentation, the findings are organized into three sub-findings corresponding to the research objectives and data collection methods.

4.1. Students' Initial Conceptual Understanding of Astronomy (Pretest – Posttest Results)

The comparative analysis of pre-test and post-test scores in Table 4 shows a statistically significant increase in students' conceptual understanding after implementing the PjBL model by utilizing Universe Sandbox. Before the intervention, most students (27 out of 32) scored within the 21-40 range, indicating limited initial comprehension of astronomical concepts.

Table 4. Pretest and Posttest Scores of Sixth-Grade Students at SDN 7 Gondosari

Score Range	Pretest Frequency	Posttest Frequency
1 – 20	0	0
21 - 40	27	0
41 - 60	5	0
61 – 80	0	12
81 - 100	0	20

Post-intervention data demonstrates remarkable progress, with no students scoring below 60. Specifically, 12 students achieved scores in the 61-80 range, while 20 students attained the highest performance level (81-100). This substantial score progression, particularly the complete elimination of failing grades and the concentration of students in the upper score ranges provides compelling evidence for the effectiveness of this integrated pedagogical approach in enhancing astronomical conceptual understanding among elementary students.

4.2. Development of Science Process Skills (Observation Results)

Systematic classroom observations were conducted to evaluate student engagement levels, learning activities, and the implementation efficacy of the PjBL model. These structured observations focused on assessing students' process skills through predetermined indicators. The observational data were subsequently analyzed to determine the effectiveness of the Universe Sandbox-assisted PjBL approach in developing elementary students' astronomical conceptual understanding.

Table 5. Student Process Skills Observation Results

No.	Indicator	Average Learning Meeting 1	Average Learning Meeting 2	Average Learning Meeting 3
1.	Observing	3.2	3.06	3.3
2.	Classifying	3	3.25	3.3
3.	Communicating	2.8	2.8	3
4.	Measuring	3.3	3.2	3.4
5.	Predicting	3.03	3.1	3.2
6.	Concluding	3.1	3.3	3.5
	Overall Average	3.06	3.14	3.3

In alignment with the qualitative dimension of this study, observations were conducted across three meetings to assess students' process skills development. The observation results in Table 5 showed progressive improvement in all six indicators: observing, classifying, communicating, measuring, predicting, and concluding. Indicators such as observing and concluding reached the highest average scores (above 3.3), showing students' enhanced abilities in identifying and interpreting astronomical events. Some difficulties were noted in measuring and predicting, especially in quantitative aspects, suggesting the need for further support in these areas. Overall, the upward trend in scores across sessions (from an average of 3.06 to 3.3) illustrates that the PjBL approach fostered students' engagement and skill application.

4.3. Statistical Analysis of Research Findings

4.3.1. Normality Test

A normality test was conducted to determine whether the pretest and posttest data were normally distributed as a prerequisite for selecting the appropriate subsequent statistical analysis. The Shapiro-Wilk test was employed for this assessment.

Table 6. Normality Test Results

Tests of Normality							
		Kolmogorov-Smirnov			Shapiro-Wilk		
	Test	Statistic	df	Sig.	Statistic	df	Sig.
Concept Understanding Test Results	Pretest	. 133	32	. 159	. 948	32	. 127
	Posttest	. 127	32	. 200*	. 952	32	. 161

Table 6 results the Shapiro-Wilk test results indicated significance values of 0. 127 for the pretest and 0. 161 for the posttest. Since all significance values exceeded the 0. 05 threshold, it can be concluded that both the pretest and posttest data followed a normal distribution.

4.3.2. Paired Sample T-Test

Subsequently, a Paired Sample T-test was performed to examine the difference between the two related datasets, specifically between pretest and post-test scores. The following results were obtained:

Table 7. Paired Sample T-test Result

Paired Samples Test									
		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Pretest - Posttest	-51. 06250	8. 99081	1. 58937	-54. 30403	-47. 82097	-32. 128	31	. 000

Table 7 results the Paired Sample T-Test yielded a Mean value of -51. 06250, indicating a decrease in average scores between the pretest and posttest the Std. a deviation of 8. 99081 suggested considerable variation among the sample scores, while the Std. Error Mean of 1. 58937 provided insight into the accuracy of the mean difference estimation. The 95% confidence interval for the difference between pretest and posttest scores ranged from -54. 30403 to -47. 82097, excluding zero, which confirms that the difference was statistically significant. The t-test result was -32. 128 with degrees of freedom (df) = 31 and a Sig. (2-tailed) value of 0. 000 (less than 0. 05), demonstrating that the difference between pretest and posttest scores was highly significant. Thus, it can be concluded that there was a statistically significant difference between the pretest and posttest results, indicating an apparent change following the intervention.

4.3.3 N-Gain Test

An N-Gain test was also conducted to measure the improvement in students' understanding of science concepts after implementing the applied learning model. The following N-Gain test results were obtained:

Table 8. N-Gain Score Test Result

Descriptive Statistics					
	N	Minimum	Maximum	Mean	Std. Deviation
N-gain_Score	32	. 53	. 95	. 7641	. 10611
N-gain_Persen	32	52. 54	94. 64	76. 4051	10. 61080
Valid N (listwise)	32				

Table 8 results the N-Gain analysis results indicate that the implemented learning model successfully enhanced students' conceptual understanding significantly, with an average N-Gain score of 0. 7486, which falls into the high category. In percentage terms, the improvement in students' understanding reached an average of 74. 86%, demonstrating a reasonably high level of effectiveness in the learning process. These findings confirm that combining PjBL with Universe Sandbox media effectively creates a conducive learning environment for comprehending astronomical concepts. However, variations in achievement levels among students were observed, with improvement rates ranging from 52. 54% to 94. 64%, indicating differing levels of responsiveness to this learning method. This disparity suggests room for further refinement, whether in optimizing instructional design, enhancing media utilization, or adjusting material difficulty levels. Overall, this study validates the effectiveness of the developed learning model and provides a strong foundation for future innovations in elementary-level science education. The results underscore the potential for continued advancements in pedagogical strategies to improve learning outcomes further.

5. Discussion

5.1. Differences in Astronomy Understanding Before and After PjBL with Universe Sandbox

This study examined the effect of the PjBL model assisted by Universe Sandbox media on students' conceptual understanding of astronomy. The results of the Paired Sample T-Test revealed a highly significant difference between pretest and post-test scores (Sig. 0. 000 < 0. 05), confirming that PJBL with Universe Sandbox effectively enhanced students' comprehension. PJBL engages students in active, PjBL, where knowledge is constructed through hands-on experience and social (Awad, 2023). Universe Sandbox facilitated direct interaction with astronomical concepts, such as planetary motion, thereby reinforcing the understanding that was previously difficult to achieve through conventional methods. Furthermore, this media heightened student engagement and motivation. According to Santos (2023), visual simulations of astronomical phenomena make learning more engaging and comprehensible. This aligns with multimodal learning theory, which posits that students process information more effectively through multiple sensory channels (visual, auditory, kinesthetic). With Universe Sandbox, students could observe astronomical concepts firsthand, significantly improving their understanding.

Tian (2023) asserts that PjBL enhances students' conceptual understanding and fosters critical and creative thinking skills. In PJBL, students actively plan and execute projects, thereby developing higher-order thinking skills in line with Bloom's taxonomy—comprehension, application, analysis, and evaluation. Through this approach, students move beyond rote memorization of astronomical concepts and instead develop the ability to analyze and evaluate astronomical phenomena in depth, as evidenced by the significant posttest score improvement. These findings align with argument that PJBL enhances knowledge and transforms students' perceptions and understanding of astronomy. The study demonstrates that PJBL supported by Universe Sandbox successfully addressed students' initial learning limitations. Cahyani (2021) also emphasize that learning is most effective when students actively engage in knowledge exploration and discovery. Using Universe Sandbox-assisted projects, students could directly observe astronomical phenomena through simulations, deepening their understanding through experiential learning and reflection.

This study also reveals that the differences in student's conceptual understanding of astronomy were influenced by cognitive factors and emotional engagement during the learning process. According to Yensy (2022) , emotional involvement enhances students' motivation to grasp complex material. Universe Sandbox was crucial in creating an exploratory and enjoyable learning experience beyond mere factual presentation. Sahin (2023) emphasizes that the most effective learning occurs when students undergo an experiential cycle of direct observation, reflection, conceptualization, and experimentation. In this context, technology is a visual aid and a bridge between theoretical knowledge and observable reality. This approach aligns with modern science education paradigms, where teachers act as facilitators guiding students in constructing knowledge independently. The findings conclude that conceptual understanding is more easily achieved when learning materials are connected to students' real-world experiences. The simulations provided by Universe Sandbox offered a relevant context for directly comprehending astronomical concepts, significantly contributing to improved understanding.

To further strengthen scientific objectivity, it is also important to acknowledge that not all studies have reported consistently positive outcomes when implementing PJBL or simulation-based media. For instance, Nirmala (2021) found that while PJBL increased student motivation, it also posed challenges in time management and group coordination, especially in larger classrooms. Similarly, Ashfahani (2020) reported that digital simulation tools sometimes led to cognitive overload among students unfamiliar with the technology, thereby hindering rather than supporting conceptual understanding. In another study, Faradillah (2022) discovered that students with low digital literacy struggled to engage with simulation-based tools effectively, resulting in minimal learning gains compared to those with stronger initial skills.

These contrasting findings underline the necessity of context-sensitive implementation. Factors such as teacher preparedness, student background, classroom management, and access to supporting infrastructure significantly influence the success of PJBL and digital simulations. Thus, while the present study demonstrates strong positive outcomes, it should not be interpreted as universally conclusive. Future research should explore differentiated instructional designs, blended media formats, or scaffolded simulation training to address such challenges.

5.2. Enhancing Astronomy Understanding Through PjBL with Universe Sandbox

This study demonstrates that the implementation of the PjBL model assisted by Universe Sandbox media significantly improved students' conceptual understanding of astronomy, with an average N-Gain score of 0. 7641 (76. 4051%), categorized as "high" and "effective." These findings align with Febryana (2023) assertion that PJBL actively engages students in exploring and solving astronomical problems while developing critical thinking skills and Namira (2024) emphasis on the importance of meaningful learning through environmental interaction. Azmi (2023) and Sakbana (2021) further support the idea that visual media such as Universe Sandbox effectively visualize complex astronomical phenomena, making them more comprehensible. Agustin (2022) also state that this media enhances student motivation through interactive simulations and PjBL.

This approach is consistent with inquiry-based learning, where students actively formulate questions, analyze data, and draw conclusions about astronomical phenomena. Oktay (2022) adds that integrating technology like Universe Sandbox supports 21st-century learning by fostering a collaborative, reflective, and technology-literate learning environment. Thus, this study proves that PJBL assisted by Universe Sandbox is effective in enhancing conceptual understanding and developing students' critical thinking and collaborative skills in learning astronomy.

The success in improving students' conceptual understanding of astronomy in this study was also influenced by the strategic role of teachers as learning facilitators. According to Fajriani (2023), social interaction between teachers and students and among students is a key element in knowledge construction. Teachers guide students through each project phase and provide regular feedback that facilitates collaborative learning through discussions and teamwork. The high N-Gain scores demonstrate that combining PjBL with Universe Sandbox media creates meaningful and compelling learning experiences. This approach goes beyond merely transferring new knowledge; more importantly, it develops essential 21st-century competencies such as critical thinking, creativity, and collaboration—increasingly vital skills in addressing the digital era's challenges.

However, to strengthen scientific objectivity and critical perspective, it is essential to recognize that not all implementations of PJBL and simulation media result in equally successful outcomes. For example, Lukitasari (2020) observed that in classrooms with limited digital infrastructure or low student digital literacy, the effectiveness of simulation-assisted PJBL was significantly reduced. Some students became more focused on exploring the media than on the underlying scientific concepts. Febryana (2023) found that the effectiveness of simulation tools in conceptual development largely depends on how well the teacher integrates the simulation with inquiry activities and conceptual scaffolding. Without proper guidance, simulations risk being treated as entertainment rather than educational tools.

Additionally, Muali (2020) report that students with weaker metacognitive skills may struggle with the open-ended nature of project-based tasks, leading to confusion or superficial understanding of the content. Time constraints in school schedules can also limit the depth of exploration possible in PJBL projects, especially when simulations involve complex data or abstract representations.

These challenges highlight that while Universe Sandbox-assisted PJBL is a powerful instructional method, its effectiveness is mediated by several contextual factors: teacher preparedness, student readiness, technological access, and curriculum design. Therefore, successful implementation requires comprehensive planning and adaptability. It is also important for future studies to investigate differentiated strategies or hybrid models that can bridge digital gaps and support diverse learners more effectively.

6. Conclusion

This study successfully demonstrates the effectiveness of the PjBL model assisted by Universe Sandbox media in enhancing elementary school students' conceptual understanding of astronomy. The results of the Paired Sample T-Test show a significant difference between pretest and post-test scores, with a significance value of 0. 000 ($p < 0.05$), confirming that this learning model has a tangible positive impact on students' conceptual understanding. Furthermore, the N-Gain analysis reinforces these findings, with an average score of 0. 7641, categorized as high, equivalent to a 76. 41% improvement, which is considered quite effective. These results indicate that the combination of PjBL and Universe Sandbox simulations successfully creates an effective learning environment for understanding abstract astronomical concepts.

Limitation

This study acknowledges several limitations that warrant consideration. First, the relatively small sample size represents only a limited subset of the elementary school student population, necessitating cautious generalization of the findings. Second, while the N-Gain analysis demonstrates significant improvement in astronomical conceptual understanding, the study did not assess the long-term retention of this learning effect. Third, the observed learning gains may partially reflect a novelty effect, where students' initial enthusiasm for innovative technology like Universe Sandbox could have contributed to temporary motivational boosts rather than solely reflecting the pedagogical model's efficacy.

Recommendation

The findings of this study provide valuable recommendations for multiple stakeholders to enhance astronomy learning in elementary education.

For students, the results emphasize the importance of active participation in PjBL through Universe Sandbox, where engaging in activities like designing projects, conducting simulations, and peer discussions can significantly improve their understanding of abstract astronomical concepts.

For educators and schools, strategic implementation is recommended. This includes the systematic adoption of PjBL for abstract scientific topics, the integration of interactive media like Universe Sandbox into lesson plans, and institutional support through adequate technological infrastructure, budget allocation for digital tools, and regular teacher professional development programs.

For future researchers, this study highlights several promising directions, including expanding research with more diverse samples across grade levels, exploring PJBL combined with other innovative digital media, conducting longitudinal studies to assess long-term academic impacts, and developing comprehensive research instruments that incorporate variables such as critical thinking and collaboration skills. These recommendations collectively aim to advance astronomy education methodologies and improve learning outcomes in elementary school settings.

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Conflict of Interest

We solemnly declare no financial, commercial, or personal relationships that could constitute a conflict of interest in this research. Data collection, analysis, and reporting phases were conducted objectively and transparently. External support has been duly acknowledged without impacting outcomes or conclusions. Findings and analyses derive solely from empirical data, and the study adheres rigorously to principles of academic integrity and scientific neutrality.

Declaration of Generative AI-assisted Technologies

This manuscript was prepared without the assistance of Generative AI. The authors conducted all intellectual contributions, critical analyses, and final revisions. The authors take full responsibility for the accuracy, originality, and integrity of the content presented in this work.

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