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DEVELOPMENT OF PBL WORKSHEETS ASSISTED BY THE STELLARIUM APPLICATION TO ENHANCE JUNIOR HIGH SCHOOL STUDENTS' CRITICAL THINKING AND COGNITIVE ABILITIES

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ABSTRACT

This study aims to develop Problem-Based Learning (PBL)-based student worksheets supported by the Stellarium application on solar system materials to enhance students' critical thinking and cognitive abilities. The research employed a quasi-experimental design with a pretest-posttest control group. Two classes participated: the experimental class used PBL-based worksheets integrated with Stellarium, while the control class used conventional worksheets. Data were collected through pretest and posttest assessments. Validation by three material experts indicated that the developed worksheets were highly feasible. The experimental class achieved medium N-gain scores for both critical thinking (g = 0.62) and cognitive abilities (g = 0.63), outperforming the control class (g = 0.40 and g = 0.23, respectively). Welch's *t*-test confirmed statistically significant differences between the groups ($p < .001$), while effect size analysis revealed strong educational effects for both critical thinking ($d = 1.08$) and cognitive abilities ($d = 1.88$). Therefore, the PBL-based worksheets supported by Stellarium are effective in improving students' critical thinking and cognitive abilities.
Keywords: student worksheets; problem-based learning; stellarium; critical thinking; cognitive abilities

INTRODUCTION

Critical thinking has emerged as one of the key competencies that learners need to effectively address the challenges of the twenty-first century. Beyond acquiring conceptual knowledge, students are expected to analyze information critically, evaluate evidence objectively, and make reasoned decisions when solving complex problems encountered in both academic and real-life contexts. According to Robert H. Ennis (2011), critical thinking is a process of reflective and rational thinking that enables individuals to determine what they should believe or how they should act, emphasizing its role as a fundamental component of effective learning and decision-making. Recognizing its importance, the Indonesian government has incorporated critical thinking into national education policies through the Independent Curriculum and the Pancasila Student Profile, in which Critical Reasoning is identified as one of the core competencies that should be systematically developed across all educational levels (Kemendikbudristek, 2022a, 2022b). Consequently, science learning should move beyond the transmission of factual knowledge by providing meaningful learning experiences that encourage

inquiry, reasoning, problem-solving, and reflective thinking through appropriate instructional strategies and learning resources.

The development of critical thinking skills among junior high school students in Indonesia remains a significant educational challenge. This is evidenced by the results of the 2018 Programme for International Student Assessment (PISA), where Indonesia ranked 74th out of 79 participating countries in science and reading literacy. Many students struggle to answer higher-order questions that require analysis, evaluation, and reasoning—hallmarks of critical thinking (OECD, 2019). Research by Putri and Hayat (2022) at SMPN 2 Karanganyar Demak revealed that only about 30% of students could correctly answer questions at the analysis and synthesis level. Furthermore, Maryani *et al*. (2020) found that, at a public junior high school in Bogor City, the average critical thinking score was only 53.07, reflecting low levels of analytical and evaluative skills. Additionally, a study by Mahmudah *et al.* (2024) showed that junior high school students' critical thinking skills related to the Solar System were also notably low. This issue stems from teaching methods that fail to engage students in the critical thinking process actively.

To meet these educational demands, a variety of instructional approaches have been proposed to enhance students' critical thinking and conceptual understanding in science. Problem-Based Learning (PBL) is widely acknowledged as an effective learner-centered approach that promotes authentic problem-solving, collaborative inquiry, and active knowledge construction. Extensive evidence indicates that PBL positively influences students' critical thinking, problem-solving competencies, conceptual understanding, and academic achievement across diverse science education settings (Arni *et al*., 2024; Noris *et al*., 2022; Sari *et al*., 2022; Syam *et al*., 2024). The effectiveness of PBL can be further strengthened through the integration of digital learning technologies that enable students to visualize abstract scientific concepts and explore phenomena that are difficult to observe directly. One promising digital learning medium is Stellarium, an interactive planetarium software that allows students to simulate astronomical phenomena, observe the motion of celestial bodies, and investigate the Solar System through authentic virtual experiences. Previous research has reported that Stellarium improves students' conceptual understanding, spatial visualization, scientific inquiry, and learning engagement by providing interactive and realistic representations of astronomical concepts (Distrik *et al*., 2024; Meirbekov *et al*., 2022; Raj *et al*., 2022; Rofik *et al.*, 2025; Xu *et al*., 2023). Collectively, these findings suggest that combining inquiry-oriented pedagogical approaches with interactive digital visualization tools has considerable potential to create more meaningful science learning experiences while supporting the development of higher-order thinking skills.

In this study, critical thinking skills and cognitive abilities are treated as distinct constructs, although both were measured using multiple-choice tests. Critical thinking skills refer to students' ability to analyze information, evaluate evidence, draw logical conclusions, and determine appropriate solutions, according to Ennis's critical thinking indicators. In

contrast, cognitive abilities refer to students' mastery of solar system concepts, as defined by Bloom's revised taxonomy, emphasizing conceptual understanding and knowledge acquisition. Accordingly, separate multiple-choice instruments were developed to measure each construct according to their respective theoretical indicators.

The effectiveness of Problem-Based Learning supported by Stellarium can be understood through contemporary learning theories that emphasize active knowledge construction and meaningful learning experiences. From a constructivist perspective, students develop conceptual understanding more effectively when they actively explore phenomena, investigate authentic problems, and construct knowledge through interaction with their learning environment rather than passively receiving information. In this context, Problem-Based Learning encourages learners to formulate hypotheses, analyze evidence, and evaluate alternative solutions, thereby fostering critical thinking and deeper conceptual understanding. The integration of Stellarium further strengthens this learning process by providing dynamic visualizations of astronomical phenomena that are otherwise difficult to observe directly, enabling students to connect abstract concepts with concrete visual experiences. The integration of PBL and the Stellarium application is expected to enhance learning through complementary instructional mechanisms. Stellarium supports students' spatial visualization by enabling them to observe and understand abstract astronomical phenomena more concretely, while PBL provides scaffolding for problem solving through structured activities involving problem identification, evidence analysis, and conclusion drawing. By combining meaningful visualization with a structured problem-solving process, this integration is expected to strengthen students' conceptual understanding as well as their cognitive abilities and critical thinking skills. The development of these learning materials is grounded in constructivist learning theories. According to Jean Piaget (1972), learners actively construct knowledge through interaction with their environment, which is supported by Lev Vygotsky (1978) and Jerome Bruner (1960), who emphasize the roles of social interaction and active discovery in learning. Furthermore, Richard E. Mayer (2009) highlights that integrating visual and verbal elements can enhance cognitive processing and support deeper understanding. Consequently, the combination of inquiry-oriented learning and interactive multimedia is expected not only to improve students' critical thinking skills but also to strengthen their cognitive abilities in learning astronomy concepts.

Despite the extensive evidence supporting the effectiveness of Problem-Based Learning (PBL) and digital learning technologies in science education, significant gaps remain in the current literature. Previous studies have predominantly focused on the effects of PBL on students' critical thinking skills or cognitive abilities as separate learning outcomes, while studies investigating the integration of interactive astronomy software such as Stellarium have primarily focused on improving conceptual understanding and learning engagement. Consequently, limited empirical evidence is available regarding the effectiveness of integrating PBL-based Student Worksheets with Stellarium to simultaneously enhance

students' critical thinking skills and cognitive abilities in astronomy learning. Furthermore, most existing studies have emphasized learning effectiveness without comprehensively evaluating the quality of the developed instructional product, students' responses toward its implementation, the magnitude of its educational impact through effect size analysis, and the relationship between critical thinking skills and cognitive abilities. These limitations indicate the need for a more comprehensive investigation that not only develops an innovative learning resource but also examines its validity, practicality, effectiveness, and educational impact within a single research framework.

Building upon these research gaps, the present study proposes an integrated learning approach through the development and implementation of PBL-based Student Worksheets assisted by Stellarium to facilitate astronomy learning. The novelty of this study lies not only in integrating an inquiry-oriented instructional model with interactive astronomical simulation software but also in evaluating the developed learning resource through a comprehensive research framework. Specifically, this study examines the validity and practicality of the developed worksheets, investigates their effectiveness in improving students' critical thinking skills and cognitive abilities, analyzes the magnitude of the instructional effect through effect size analysis, explores the relationship between critical thinking and cognitive abilities, and evaluates students' responses toward the implemented learning approach.

The research questions are as follows: (1) How appropriate are the Stellarium-based Problem-Based Learning Worksheets as independent teaching material for junior high school students on the solar system? (2) What are the differences in students' critical thinking skills between the experimental and control classes? (3) How effective are the Stellarium-based Problem-Based Learning Worksheets in improving students' critical thinking skills? (4) What are the differences in students' cognitive abilities between the experimental and control classes? (5) How effective are the Stellarium-based Problem-Based Learning Worksheets in improving students' cognitive abilities? (6) What is the correlation between cognitive abilities and critical thinking skills? (7) What are the perceptions of students whose learning uses the Stellarium-based Problem-Based Learning Worksheets?

Therefore, this study aims to develop PBL-based worksheets supported by the Stellarium application to improve junior high school students' critical thinking skills and cognitive abilities in learning the solar system. The developed worksheets cover topics including the Earth's rotation and revolution, solar and lunar eclipses, and the Moon's revolution around the Earth for seventh-grade students. It is anticipated that this study will contribute to the advancement of innovative, technology-enhanced learning strategies and support the improvement of science education at the junior high school level.

METHOD

This study adopted a Research and Development (R&D) approach based on the ADDIE model, which comprises five phases: Analysis, Design, Development, Implementation, and Evaluation, as proposed by Dick and Carey (2009). This

model is widely recognized for its effectiveness in the development of educational tools. It was chosen for its systematic and flexible nature, making it particularly suitable for creating Problem-Based Learning (PBL) worksheets integrated with technology, such as the Stellarium application. The study employed a quasi-experimental pretest–posttest control group design.

The research was undertaken at a junior high school in Bandung Regency during the period of November 6–14, 2025. The study population consisted of seventh-grade students enrolled at the school. The participants were divided into two groups: 42 students from Class VII B formed the control group, while 41 students from Class VII D constituted the experimental group. This school was selected because its characteristics aligned with the objectives of the research. Additionally, this school offers parallel classes with relatively homogeneous student populations, which facilitated the quasi-experimental research design. The school administration and subject teachers provided their permission and full support for the research, ensuring its optimal implementation. A purposive sampling technique was employed to select participants who met specific criteria established in accordance with the research objectives. Two classes were chosen because they had traits that matched the research requirements and supported app-assisted learning, as most students owned smartphones. The experimental group used PBL-based worksheets integrated with the Stellarium app, while the control group used conventional worksheets without the application. Class selection was conducted through discussions with the science teachers.

The PBL implementation was conducted in a single learning session lasting two class periods (2 × 40 minutes). The time allocation for each PBL stage was flexible and adapted to the learning process, with the investigation and data collection stage receiving the largest proportion of the lesson. The teacher acted as a facilitator by providing instructions on the use of the Stellarium application and guiding students throughout the investigation and problem-solving processes. Subsequently, students worked collaboratively in groups to observe astronomical phenomena using Stellarium, discuss their observations, analyze the given problems, and complete the activities in the PBL-based student worksheet.

The validity and reliability of this study were examined using student pretest scores. The instrument employed was a 20-item multiple-choice test. Items 1-5 and 11-15 assessed cognitive abilities, while items 6-10 and 16-20 evaluated critical thinking skills. The validity test results indicated that the correlation coefficient (r) for each item ranged from 0.298 to 0.514. All items demonstrated a significance value of Sig. <0.05, leading to the conclusion that they were valid and suitable for measuring both cognitive and critical thinking abilities. The reliability test produced a Cronbach's Alpha value of 0.689, placing it in the high category and signifying that the multiple-choice test instrument is reliable and appropriate for assessing students' cognitive and critical thinking skills.

This study employed intact classes as the units of treatment; therefore, a potential cluster effect cannot be completely ruled out because students within the same class may share similar

learning characteristics and experiences. However, the limited number of classes involved in this study did not permit the application of multilevel analysis. Future studies involving a larger number of classes are recommended to employ multilevel analysis to account for clustering effects and provide more robust estimates of the intervention's effectiveness.

Data collection techniques included a subject matter expert validation questionnaire to assess the appropriateness of the worksheets, a student readability questionnaire to evaluate the students' understanding of the language, instructions, and presentation of the developed worksheets, a teacher response questionnaire to gauge the worksheets' appropriateness, and cognitive ability and critical thinking skills tests to assess students' abilities before and after the intervention. Furthermore, a student response questionnaire was administered to collect students' perceptions of learning with the PBL-based worksheets integrated with the Stellarium application.

The PBL-based student worksheets integrated with the Stellarium application were designed and developed using the ADDIE framework, which includes the stages of analysis, design, development, implementation, and evaluation. Instrument testing techniques employed included feasibility percentage calculations, question validity and reliability tests, and readability percentage assessments for the PBL Worksheets. The data analysis techniques used in this study comprised normality tests, homogeneity tests, N-gain tests, Welch's t-tests, effect size calculations, linearity tests, and correlation tests.

RESULTS AND DISCUSSION

Feasibility of the PBL Student Worksheets

The feasibility of the PBL-based student worksheets was evaluated using a validation questionnaire administered to subject matter experts. This worksheets, focusing on the solar system, was assessed by three lecturers from the Physics Education Study Program at Universitas Pendidikan Indonesia. The subject matter expert validation test for the PBL student worksheets achieved a score of 100%, categorizing it as very feasible. Additionally, the validation test for the accompanying assessment instrument received a score of 95.66%, also marking it as very feasible. Furthermore, the worksheets was evaluated by three junior high school science teachers, who gave a response score of 88.67%, indicating it was considered very feasible. The readability of the PBL-based student worksheets was tested with a student readability questionnaire before its pilot implementation with the students in the experimental class. The readability test yielded a score of 80.48%, classifying the worksheets as easy to read.

As part of the preliminary data analysis, the distribution of the data was examined using the Shapiro–Wilk test in SPSS to determine whether the assumptions of normality were satisfied. The analysis was conducted for the cognitive abilities and critical thinking scores of both the experimental and control groups. All significance values (Sig.) were found to be above 0.05, confirming that the assumption of normality was fulfilled and that the data were appropriate for parametric statistical analysis. In addition, a homogeneity of variance test was performed to determine whether the variances across the groups were

statistically equivalent. This test is essential for validating the use of parametric statistical procedures, including the *t*-test and analysis of variance (ANOVA), which require the assumption of homogeneity of variance. In this study, the homogeneity of variance for cognitive ability scores was evaluated using Levene's test, which produced a significance value of 0.020 based on the mean. Since this value is less than 0.05 (0.020 < 0.05), we conclude that the variances of the cognitive data between the groups are not homogeneous. Additionally, Levene's test was also performed to examine the homogeneity of variance for the critical thinking skill scores, yielding a significance value of 0.013 based on the mean. This value, too, is less than 0.05 (0.013 < 0.05), indicating that the variances of the critical thinking data between groups are not homogeneous. These findings suggest that the two sample groups have different (unequal) variances.

Critical Thinking Skills Improvement

After verifying that the data satisfied the assumption of normality, normalized gain (N-Gain) scores were determined using Microsoft Excel. This analysis was conducted to measure students' improvement from the pretest to the posttest and to examine differences in learning gains between the experimental and control groups. The results of the N-Gain analysis for critical thinking skills and cognitive abilities are presented in Tables 1 and 2, respectively.

Table 1: Results of the Critical N-Gain Test for the Experimental and Control Classes

Class	**⟨Pretest⟩**	**⟨Post test⟩**	**⟨*g*⟩**	**Criteria**
Experi-mental	65,12	87,31	0,62	Medium
Control	60,47	76,19	0,40	Medium

Critical Thinking Skills Effectiveness

Statistical analyses were performed to examine the effectiveness of the Stellarium-assisted PBL student worksheets in enhancing students' critical thinking skills. Welch's *t*-test was subsequently conducted to compare the post-intervention mean scores of the experimental and control groups and determine whether the observed differences were statistically significant. Additionally, to quantify the strength of the treatment's effect, we conducted a non-statistical test to calculate the effect size. This analysis not only indicates whether a significant difference exists but also provides insight into the strength of the treatment's influence on improving students' critical thinking skills.

Welch's *t*-test serves as an alternative to the independent-samples *t*-test for comparing the mean scores of two independent groups when the assumption of equal variances is violated. This test is commonly employed to compare the results of two groups receiving different treatments: the control class utilizing conventional worksheets and the experimental class employing PBL-based worksheets. The results of the Welch's t-test using SPSS can be seen in Table 2 for critical thinking skills.

Table 2: Results of the Critical Welch's T-Test for the Control and Experimental Classes

Critical	**Statistic[a]**	**df1**	**df2**	**Sig.**
Welch	24.376	1	75.642	<0,001

Effect Size calculations are used to determine the extent of influence (strength of effect) of a treatment, namely, PBL-based worksheets in the experimental class and conventional worksheets in the control class. Effect Size calculations using SPSS can be seen in Table 3 for critical thinking skills.

Table 3: Results of the Critical Effect Size Calculations for Experimental & Control Classes

M Experimental	M Control	SD Experimental	SD Control	SD pooled	Cohen's d	Criteria
87,32	76,19	8,667	11,677	10,301	1,080	Strong Effect

Cognitive Abilities Improvement

The results of the N-Gain calculation can be seen in Table 4 for cognitive abilities.

Table 4: Results of the Cognitive N-Gain Test for the Experimental and Control Classes

Class	⟨Pretest⟩	⟨Post test⟩	⟨g⟩	Criteria
Experi-mental	57,31	85,85	0,63	Medium
Control	53,57	64,28	0,23	Low

Cognitive Abilities Effectiveness

The effectiveness of implementing PBL student worksheets assisted by the Stellarium application in this study was analyzed using statistical tests to evaluate the treatment's impact on students' cognitive abilities. The effectiveness of the intervention was assessed using Welch's *t*-test to examine whether the experimental and control groups differed significantly in their mean posttest scores. Additionally, to quantify the strength of the treatment's effect, we conducted a non-statistical test to calculate the effect size. This analysis not only indicates whether a significant difference exists but also provides insight into the strength of the treatment's influence on improving students' cognitive abilities.

The results of the Welch's t-test, conducted using SPSS, are presented in Table 5, which details the cognitive abilities of the control and experimental classes.

Table 5: Results of the Cognitive Welch's T-Test for the Control and Experimental Classes

Cognitive	Statistic[a]	df1	df2	Sig.
Welch	74.215	1	73.170	<0,001

Effect Size calculations using SPSS can be seen in Table 6 for cognitive abilities.

Table 6: Results of the Cognitive Effect Size Calculations for Experimental & Control Classes

M Experimental	M Control	SD Experimental	SD Control	SD pooled	Cohen's d	Criteria
85,85	64,28	9,213	13,278	11,452	1,883	Strong Effect

Correlation

Before conducting a correlation test, a linearity test is first performed. The linearity test is a prerequisite for analysis, aimed at determining whether the relationship between the independent and dependent variables is linear. This test is essential before conducting a Pearson correlation analysis or linear regression, as both require a linear relationship. The results of the linearity test in the experimental class indicated a linear relationship, allowing for regression or correlation analysis.

A Pearson product–moment correlation analysis was performed using SPSS to examine the relationship between students' cognitive abilities and critical thinking skills by determining the strength and direction of the association. The results are presented in Table 7.

Table 7: Correlation Test Results

Class	r	Sig.	Category	Description
Experi-mental	0,273	0,084	Low	Not Significant

The Pearson product–moment correlation analysis conducted in the experimental group yielded a correlation coefficient (*r*) of 0.273 with a significance

value (Sig. 2-tailed) of 0.084. The positive coefficient indicates a positive association between cognitive ability and critical thinking skills, suggesting that higher cognitive ability tends to be accompanied by higher critical thinking skills. However, the correlation was weak, and the significance value exceeded the 0.05 threshold, indicating that the association between the two variables was not statistically significant. Therefore, no significant association was found between cognitive ability and critical thinking skills in the experimental group.

Student Perceptions

Student perceptions were obtained from a questionnaire of student responses to the Stellarium-assisted PBL worksheets administered to 41 students in the experimental class. The results of the student response questionnaire can be seen in Table 8.

Table 8: Student Response Results

Student Response Score	**Total Score**	**Student Response (%)**	**Description**
1780	2050	86,82	Very Positive

Based on the results of the student response questionnaire, these PBL-based worksheets received positive comments and suggestions, as shown in Table 9.

Table 9: Student Comments and Suggestions

No.	**Comments and Suggestions**
1	Worksheets are easy to use, only the Stellarium application is a bit difficult to operate
2	Increase the decorations and pictures in the worksheets
3	The duration of learning should be increased because it is fun and interesting

The observed improvements in cognitive abilities and critical thinking skills can be attributed to the combined influence of three interrelated factors: the use of the Stellarium application, the implementation of PBL-based worksheets, and the integration of both within the learning process.

First, regarding the Stellarium application, students' abilities improved significantly due to its capability to provide concrete, dynamic, and realistic visualizations of astronomical objects and phenomena. Abstract concepts, such as Earth's rotation, Earth's revolution, the apparent motion of the Sun, and the positions of constellations, became easier to understand when visualized directly. This visualization helped reduce students' cognitive load by allowing them to focus on phenomena that cannot be directly observed, thereby accelerating their conceptual understanding. Additionally, the exploratory nature of Stellarium enabled students to conduct independent investigations, such as observing changes in the positions of the Sun or constellations at specific times and locations. These exploratory activities fostered curiosity, questioning skills, and investigative abilities, which are all essential components of critical thinking.

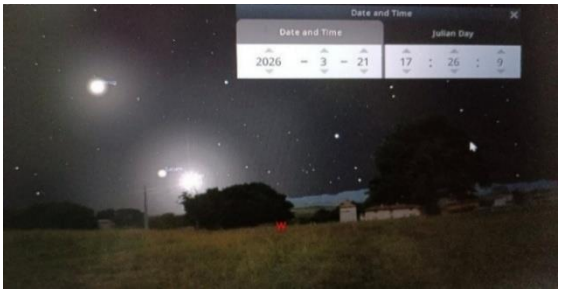


Figure 1: Position of the Sun at Sunset

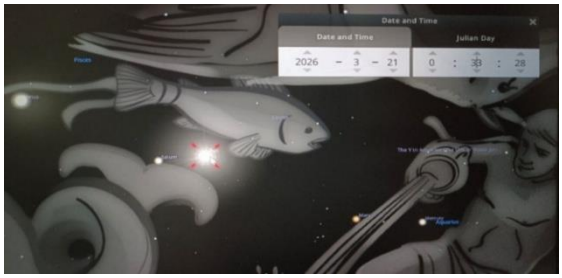


Figure 2: Constellations of the Sun Background

The interactivity offered by Stellarium played a significant role in enhancing students' engagement in the learning process. Rather than being passive recipients of information, students actively participated by operating the application, making observations, and drawing conclusions from the simulations displayed. This high level of engagement positively influenced their motivation to learn and improved the quality of information processing. Additionally, the accuracy of the simulations in Stellarium helped reduce common misconceptions in astronomy, such as misunderstandings about the causes of day and night or seasonal changes. By observing representations that closely reflect actual conditions, students were able to correct inaccurate understandings and build more scientifically accurate cognitive frameworks.



Figure 3: Solar Eclipse

The use of the Stellarium application in learning, especially regarding solar eclipse phenomena, offers significant advantages through realistic and dynamic astronomical visualizations. By providing displays that closely resemble actual conditions, students can directly observe the positions of the Sun and the Moon during an eclipse. This visualization helps to clarify abstract concepts, such as the relative positions of celestial bodies and the process of an eclipse, enabling students to not only memorize information but also develop a deeper understanding through visual representations. As a result, this approach enhances students' cognitive abilities.

The findings of this study are consistent with previous research showing that Stellarium enhances students' understanding of astronomy through interactive and realistic visualizations, while also increasing their learning interest, conceptual understanding, and scientific literacy (Pilendia, 2022; Freitas *et al*., 2021; Ayomi *et al*., 2025). Extending these findings, the present study demonstrates that integrating Stellarium into Problem-Based Learning (PBL)-based worksheets not only supports students' cognitive abilities but also improves their critical thinking skills. These results suggest that combining astronomy visualization technology with a problem-based learning approach provides more comprehensive educational outcomes than using visualization tools alone.



Figure 4: Lunar Eclipse

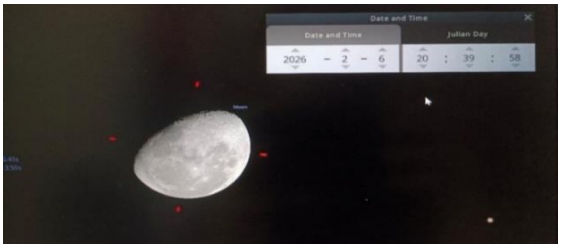
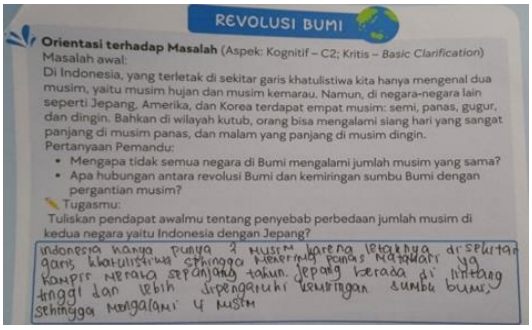


Figure 5: Moon Phase

Stellarium offers a time simulation feature that allows students to observe the eclipse processes and the phases of the Moon progressively. By manipulating time, students can analyze the cause-and-effect relationships behind these phenomena, such as why eclipses occur only at specific times and why lunar eclipses can only happen during the full moon phase. This not only enables students to conduct observations but also teaches them to interpret information scientifically. These activities foster critical thinking skills, particularly in analysis and reasoning. Research conducted by Maulana and Masturi (2023) demonstrated that Stellarium-assisted astronomy learning effectively enhances students' conceptual understanding and digital literacy through interactive visualization and exploration-based activities. The use of Stellarium allows students to observe astronomical phenomena dynamically and realistically, facilitating a deeper understanding of concepts. Therefore, the integration of dynamic visualization, interactive simulation, and exploratory activities significantly contributes to improving students' cognitive abilities and critical thinking skills.

Second, from the perspective of problem-based learning (PBL) worksheets, a key advantage is the presentation of contextual problems directly related to real-world phenomena, such as the differences in the number of seasons experienced by various countries. These contextual problems serve as learning triggers and stimulate higher-order thinking skills, as students are required to analyze situations, connect concepts, and formulate logical solutions. This contributes directly to the enhancement of cognitive abilities, particularly in understanding, application, and analysis, while also promoting the development of critical thinking skills.

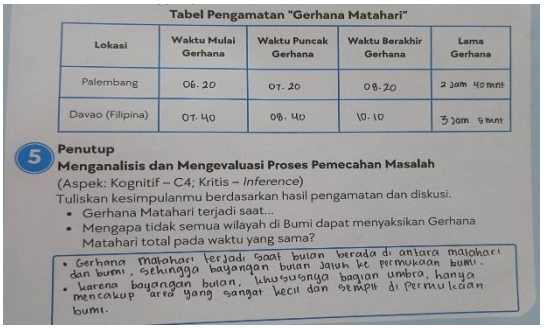

REVOLUSI BUMI

Orientasi terhadap Masalah (Aspek: Kognitif – C2; Kritis – *Basic Clarification*)
Masalah awal:
Di Indonesia, yang terletak di sekitar garis khatulistiwa kita hanya mengenal dua musim, yaitu musim hujan dan musim kemarau. Namun, di negara-negara lain seperti Jepang, Amerika, dan Korea terdapat empat musim: semi, panas, gugur, dan dingin. Bahkan di wilayah kutub, orang bisa mengalami siang hari yang sangat panjang di musim panas, dan malam yang panjang di musim dingin.
Pertanyaan Pemandu:
- Mengapa tidak semua negara di Bumi mengalami jumlah musim yang sama?
- Apa hubungan antara revolusi Bumi dan kemiringan sumbu Bumi dengan pergantian musim?

Tugasmu:
Tuliskan pendapat awalmu tentang penyebab perbedaan jumlah musim di kedua negara yaitu Indonesia dengan Jepang?

Figure 6: Contextual Problems of PBL Worksheets on Earth's Revolution Material

Problem-Based Learning (PBL)-based worksheets guide students through stages of problem orientation, investigation, solution development, and evaluation, providing a constructivist learning experience that encourages active knowledge construction. Through these processes, students are expected to analyze, evaluate, and present arguments based on evidence, thereby promoting deeper cognitive engagement. These findings are consistent with those of Robert H. Ennis (2011), who argued that PBL-based worksheets promote critical thinking by fostering elementary clarification, basic inference, advanced clarification, and strategic and tactical thinking.


Tabel Pengamatan "Gerhana Matahari"

Lokasi	Waktu Mulai Gerhana	Waktu Puncak Gerhana	Waktu Berakhir Gerhana	Lama Gerhana
Palembang	06.20	07.20	08.20	2 jam 40 mnt
Davao (Filipina)	07.40	08.40	10.10	3 jam 5 mnt

5 Penutup
Menganalisis dan Mengevaluasi Proses Pemecahan Masalah
(Aspek: Kognitif – C4; Kritis – *Inference*)
Tuliskan kesimpulanmu berdasarkan hasil pengamatan dan diskusi.
- Gerhana Matahari terjadi saat...
- Mengapa tidak semua wilayah di Bumi dapat menyaksikan Gerhana Matahari total pada waktu yang sama?

Figure 7: Example of a Group Worksheet Response on the Solar Eclipse Topic

As qualitative evidence, students' responses in the PBL-based worksheet indicate that they were able to construct

scientific explanations based on observations using the Stellarium application. For example, one student concluded that a solar eclipse occurs when the Moon is positioned between the Sun and the Earth and explained that not all regions can observe a total solar eclipse because the Moon's umbral shadow covers only a limited area of the Earth's surface. This response suggests that the integration of Stellarium visualization and PBL activities supported students' conceptual understanding and scientific reasoning.

On the other hand, the conventional worksheets used in this study facilitated two-way interaction through question-and-answer activities, simple discussions, and the integration of instructional media like learning videos and teaching aids. However, the nature of these learning activities was mainly limited to structured questions that directed students toward specific answers. As a result, they did not fully encourage students to conduct independent investigations or develop in-depth arguments. From Ennis's perspective, conventional worksheet activities generally remain at the levels of elementary clarification and sometimes basic inference, such as identifying information and drawing direct conclusions from available sources. Therefore, the primary difference between the two types of worksheets lies not only in the level of interaction but also in the depth of the thinking processes they promote. PBL-based worksheets offer broader opportunities for students to develop all aspects of critical thinking, leading to greater improvements in cognitive abilities and critical thinking skills than conventional worksheets.

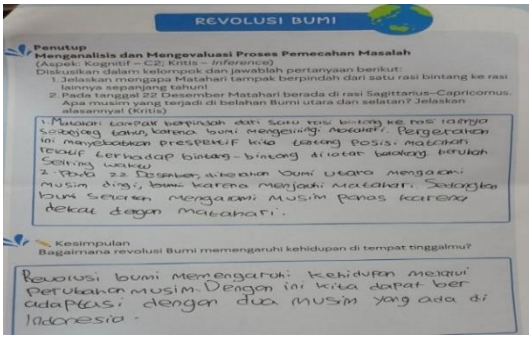


Figure 8: PBL Worksheets Stage: Analyze and Evaluate the Problem Solving Process

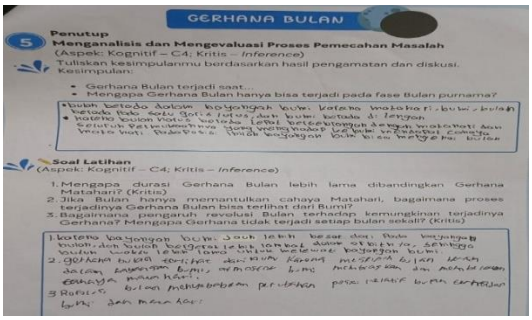


Figure 9: PBL Worksheets Practice Questions on Lunar Eclipse Material

This sequence of stages enables students to actively construct their own knowledge, leading to a deeper conceptual understanding. Additionally, collaborative activities like group discussions foster intensive academic social interactions, such as exchanging ideas, defending arguments, and evaluating peers' opinions. These interactions are crucial for developing critical thinking skills, particularly in the areas of interpretation, analysis, and evaluation. The systematic and well-structured design of the worksheets serves as scaffolding that guides students through sequential stages of thinking, allowing them not only to grasp concepts but also to build a comprehensive and logical understanding.

Third, the integration of Problem-Based Learning (PBL)-based worksheets with the Stellarium application has proven to be a key factor in enhancing the effectiveness of learning. The alignment between the problems presented in the worksheets and the visualizations provided by Stellarium

allows students to directly test and verify the results of their reasoning. For instance, when students are asked to analyze the position of the Sun during sunset in a specific region, they can immediately observe the simulation through Stellarium. This connection bridges abstract thinking with concrete evidence, making the learning process more profound and meaningful. It also supports meaningful learning, enabling students to relate the concepts learned to real-world and contextual experiences, thus enhancing long-term retention and conceptual understanding.

The integration of PBL-based worksheets and the Stellarium application promotes student-centered, exploration-based learning, enabling students to actively construct knowledge while fostering independence, metacognitive abilities, cognitive development, and critical thinking skills. These findings are supported by Langendorf, Schneider, and Hessman (2022), who reported that digital astronomy tools enhance students' conceptual understanding, digital competencies, active engagement, and scientific reasoning through learner-centered activities.

The findings demonstrate that PBL-based student worksheets supported by the Stellarium application effectively improve students' cognitive abilities and critical thinking skills by engaging them in scientific analysis and contextual problem-solving. These results are consistent with the findings of Anazifa and Djukri (2017), who reported that PBL enhances critical thinking and conceptual understanding, as well as Freitas *et al*. (2021), who showed that Stellarium facilitates the visualization of abstract astronomy concepts. Overall, integrating PBL with the Stellarium application provides meaningful learning experiences and supports higher-quality science instruction.

The Stellarium application strengthens students' cognitive abilities by providing interactive and realistic visualizations that make abstract solar system concepts easier to understand. These findings are consistent with Albrecht and Galasso (2024), who reported that Stellarium helps students visualize celestial objects and understand astronomical phenomena that are difficult to observe directly, as well as Li and Patton (2025), who found that digital planetarium software enhances conceptual understanding through realistic, engaging, and interactive simulations.

CONCLUSION

Based on the research and development of a PBL-based worksheets using the Stellarium application for studying the solar system, which aimed to enhance students' critical thinking skills and cognitive abilities, the following conclusions can be drawn: 1) The validation tests conducted by subject matter experts, teacher feedback, and student readability assessments indicate that the PBL-based worksheets utilizing the Stellarium application is highly suitable for implementation as teaching material in schools. 2) The N-Gain analysis of critical thinking skills reveals that the experimental class, which used the PBL-based worksheets with the Stellarium application, showed greater improvement than the control class that utilized conventional worksheets. 3) Statistical analysis results, including Welch's t-test and effect size calculations, confirm that learning through the PBL-based worksheets with the Stellarium application

in the experimental class effectively enhances students' critical thinking skills compared to the conventional methods used in the control class. 4) The N-Gain analysis of cognitive abilities demonstrates that the experimental class, using the PBL-based worksheets with the Stellarium application, experienced greater improvement than the control class with conventional worksheets. 5) According to the statistical analysis, including Welch's t-test and effect size calculations, it can be concluded that the instructional approach using PBL-based worksheets with the Stellarium application effectively improves students' cognitive abilities compared to conventional methods. 6) The correlation test results between cognitive ability and critical thinking skills in the experimental class indicate a positive, albeit not statistically significant, relationship. This implies that cognitive ability does not significantly correlate with critical thinking skills, suggesting that other factors may influence students' critical thinking development. 7) Students' feedback on the PBL-based worksheets using the Stellarium application was 86.82%, indicating a very positive response.

The findings of this study have practical implications for the broader implementation of PBL-based student worksheets assisted by the Stellarium application. Effective implementation requires adequate technological resources and teacher training to support the integration of Stellarium into PBL activities, thereby enhancing the sustainability and scalability of the intervention across different school contexts. This study did not examine potential moderating or mediating variables; therefore, future research is recommended to investigate factors such as students' initial ability levels and the frequency of Stellarium use to better explain variations in learning outcomes. Schools are encouraged to provide short teacher training programs and develop practical guidelines for integrating Stellarium into astronomy lessons to promote consistent and effective classroom implementation.

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