Copyright © The Author(s) 2026
Jurnal Pembelajaran IPA Terpadu: PELITA 6(2), July – December 2026

Effect of the STEM Approach on Students' Conceptual Understanding in IPAS Learning on the Properties of Light in Elementary School

Jani Nur Rohani [1*], Sandi Budi Iriawan [2], Aprilia Eki Saputri [3]

[1, 2, 3] Universitas Pendidikan Indonesia, Indonesia

* janinuari.5@upi.edu

Abstract

The urgency of this study lies in the need to strengthen elementary students' conceptual understanding of light properties through an engaging and contextual STEM approach. Conceptual understanding of the Properties of Light among elementary school students remains challenging when learning is predominantly oriented toward verbal explanations and provides limited investigative experience. This study aimed to analyze changes in fifth-grade students' conceptual understanding after participating in Science, Technology, Engineering, and Mathematics (STEM) learning on the Properties of Light. The study employed a quantitative approach with a pre-experimental one-group pretest-posttest design. The sample consisted of 35 fifth-grade students at SD Negeri Sukamantri, Bandung Regency, selected purposively. Conceptual understanding was measured using 10 essay questions covering seven indicators: interpreting, classifying, explaining, inferring, comparing, summarizing, and exemplifying. The mean score increased from 46,57 on the pretest to 85,14 on the posttest. All students obtained higher posttest scores than pretest scores. The Wilcoxon Signed-Rank Test yielded Z = -5,163 with a two-sided exact p-value < 0,001 and an effect size of r = 0,873. The mean N-Gain was 0,7156 or 71,56%, which was classified as high. Improvement also occurred across all indicators of conceptual understanding, with changes ranging from 35-41 percentage points. These findings indicate a substantial within-group improvement in conceptual understanding following STEM learning. However, because the study did not use a comparison group, the results should be interpreted as evidence of within-group change rather than as a causal estimate that fully isolates the effect of STEM from other factors.

Keywords: *STEM, Conceptual Understanding, Properties Of Light, IPAS, Elementary School.*

Introduction

Elementary education is a fundamental stage in shaping students' ways of thinking, scientific attitudes, and ability to make sense of everyday phenomena. At this stage, science learning should not be limited to the mastery of facts or memorization, but should provide students with opportunities to build relationships among concepts, explain the reasons behind phenomena, and apply knowledge in new situations. These demands are increasingly relevant in twenty-first-century education, which positions critical thinking, creativity, communication, collaboration, scientific literacy, and problem solving as essential competencies (Prasetyo et al., 2021; Tohani & Aulia, 2022). In science learning, conceptual understanding is fundamental because it determines students' ability to interpret evidence, construct explanations, develop reasoning, and apply knowledge meaningfully. Therefore, successful science learning is reflected not only in achievement scores, but also in students' ability to construct scientific meaning and connect it with real experiences.

https://doi.org/10.54065/pelita.6.2.2026.1811

The urgency of strengthening conceptual understanding and scientific literacy in Indonesia is reflected in the 2022 Programme for International Student Assessment (PISA) The Indonesian students had an average science score of 383, still below the OECD average of 485, and only about 34% of Indonesian students reached at least Level 2 (OECD, 2023). At this level, students are expected to recognize appropriate explanations for familiar scientific phenomena and use scientific knowledge to evaluate simple conclusions based on data. This condition indicates that the challenge of science education is not only related to the amount of content mastered, but also to the ability to use concepts to explain, interpret, and solve problems. The previous studied also highlighted Indonesian students' difficulties in contextualizing scientific knowledge in everyday life (Yusmar & Rizka, 2023). Therefore, learning needs to be more active and contextual and should provide space for empirical experiences in building understanding.

Within the Merdeka Curriculum, this need is accommodated through Natural and Social Sciences (IPAS), which emphasizes integrated and contextual understanding of phenomena. In Phase C, students are expected not only to recognize scientific concepts but also to use them to observe, question, investigate, and explain phenomena in their surroundings. However, the implementation of IPAS learning still faces challenges. Learning dominated by teacher explanations and textbook use can position students as passive recipients of information, while opportunities for observation, experimentation, and investigation remain limited (Irsan, 2021). Practical activities may also be constrained by limited facilities, restricted instructional time, and technical readiness for implementation (Buabeng et al, 2025). Under such conditions, scientific concepts risk being understood as verbal information to be memorized rather than as knowledge constructed through relationships among evidence, representations, and experience. IPAS learning therefore requires an approach that is concrete, structured, and oriented toward problem solving.

One topic that requires such learning experiences is the Properties of Light. This topic includes the rectilinear propagation of light, reflection, refraction, the ability of light to pass through certain materials, and light dispersion. Although these phenomena are closely related to everyday life, their scientific explanations are not always easy to understand because students must connect what they observe with concepts that are partly abstract. These difficulties can lead to partial understanding or misconceptions. The previous studied identified misconceptions among fifth-grade students regarding the Properties of Light, while the previous studied reported that elementary school students may hold conceptions of light phenomena that are inconsistent with scientific explanations (Belousova et al., 2026; Nurfiyani et al., 2020). A similar condition was identified in the preliminary study at SD Negeri Sukamantri, Bandung Regency. The classroom teacher reported that some students still had difficulty explaining the movement of light, refraction, and applications of light properties. Some initial responses also explained rainbows without relating them to refraction and dispersion, indicating incomplete conceptual understanding. These preliminary findings were not treated as an independent diagnosis of misconceptions, but rather as contextual evidence that students still faced a gap between the ability to state facts and the ability to explain conceptual relationships. This strengthens the need for learning that enables students to test their initial ideas through empirical evidence and systematically connect observations with scientific explanations.

Conceptual understanding in this study is viewed as an ability that extends beyond remembering information. The understanding is represented by seven cognitive processes: interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining.

These seven processes are relevant to the Properties of Light because students need not only to know that light can be reflected or refracted, but also to interpret observations, classify objects based on their interactions with light, provide examples, summarize experiments, draw inferences, compare optical phenomena, and explain cause-and-effect relationships. This framework allows changes in learning to be analyzed more specifically. Total scores provide a general overview, while achievement for each indicator shows which aspects of understanding develop more strongly or still require reinforcement. Thus, measurement based on the seven indicators provides a more comprehensive picture of changes in students' cognitive abilities.

The Science, Technology, Engineering, and Mathematics (STEM) approach offers a relevant framework for addressing these needs because it integrates several disciplines in meaningful problem solving (Subramaniam et al., 2025). Science provides the foundation for understanding phenomena; technology supports investigation and application of concepts; engineering provides opportunities to design, build, test, and improve solutions; and mathematics is used for measurement, calculation, comparison, and quantitative reasoning. This integration positions students as users of concepts rather than merely recipients of information. The systematic review by sshowed that integrated STEM is associated with diverse K-12 learning outcomes, including knowledge acquisition, higher-order thinking, attitudes, and problem solving, although the outcomes depend on the form of integration, student characteristics, activity design, and the outcomes measured. Therefore, using the STEM label alone is insufficient; its effectiveness needs to be examined through clear connections among learning activities, the concepts being studied, and learning outcome indicators.

For the topic of light, STEM integration can be implemented through optical experiments and simple engineering tasks. Direct investigation of reflection, refraction, light propagation, and dispersion allows students to compare predictions with observed results. These concepts can then be applied through the design of a simple periscope that uses reflection from plane mirrors. Students need not only to know that light can be reflected, but also to understand how the position and orientation of mirrors determine the direction of light and the function of the device. The Engineering dimension strengthens this process through stages of understanding the problem, developing a design, building a prototype, testing, evaluating, and improving the design. The previous studied showed that the engineering design process among elementary school students involves thinking and decision making that develop through problem-solving experiences (Sung & Kelley, 2022). STEM worksheets on periscope material; therefore, the novelty of this study does not lie in the use of a periscope itself, but in the use of an investigative and engineering sequence to examine changes in conceptual understanding in a structured manner (Mardita et al., 2022).

Previous studies generally support the potential of STEM, although they vary in focus and design. The previous studied reported benefits of STEM integrated with Project-Based Learning for elementary students' creativity and science conceptual understanding (Yulaikah & Rahayu, 2022). The implemented STEM in fifth-grade learning about electric circuits and power generation (Helga et al., 2024). The developed a STEM-based IPAS teaching module to support basic scientific thinking skills (Puspitasari et al., 2024). On the topic of light, the previous studied showed that STEM-based guided inquiry improved conceptual understanding of light and scientific explanation ability in a design with a comparison group (Nasir et al., 2022). STEAM approach can support elementary students' conceptual understanding of scientific phenomena.

These findings confirm the relevance of STEM, but do not fully explain how understanding of the Properties of Light in the context of Phase C IPAS changes across different cognitive indicators (Corrigan et al., 2025). Based on this synthesis, three research gaps can be identified. First, there is a contextual gap: several elementary-level studies have examined electricity, module development, creativity, or scientific thinking skills, whereas studies on the Properties of Light in Phase C IPAS remain relatively limited. The previous studied did use a periscope, but their study focused on the development and feasibility of learning materials rather than on changes in seven indicators of understanding through a pretest-posttest analysis (Mardita et al., 2022). Second, there is an outcome gap: many studies report learning outcomes, creativity, critical thinking, or aggregated understanding scores, so patterns of change in specific cognitive processes are not visible (Tampubolon & Megalina, 2025).

Third, there is a mechanism gap: the relationship between Science, Technology, Engineering, and Mathematics activities and the development of particular indicators of understanding has not always been explained specifically. Indicator-level analysis is important because direct observation and classification activities are closely related to classifying ability, explanation-building activities relate to explaining and inferring, while periscope engineering requires students to compare alternatives, apply examples of reflection concepts, and evaluate test results. Based on these gaps, the contribution of this study is positioned in the integration of investigations of the Properties of Light with the periscope engineering process in Phase C IPAS learning and in the evaluation of changes in understanding through seven cognitive indicators. This contribution differentiates the study from instructional-material development studies that primarily assess validity or practicality and from STEM studies that report only aggregate scores.

The study aimed to analyze changes in fifth-grade students' conceptual understanding of the Properties of Light before and after participating in STEM learning. Specifically, it addressed three questions: (1) What was students' conceptual understanding before the implementation of STEM? (2) What was students' conceptual understanding after the implementation of STEM? and (3) Was there a significant increase in conceptual understanding between before and after the learning process? Because the study used a pre-experimental one-group pretest-posttest design, the results are positioned as evidence of within-group change after the intervention rather than as a causal estimate that fully separates the effect of STEM from other factors. This position maintains proportional interpretation while allowing patterns of change in each indicator to be discussed more informatively. Thus, the empirical novelty of this study lies not in the use of STEM as a new approach, but in the more detailed mapping of the intervention and learning outcomes to provide a more informative explanation of the development of students' conceptual understanding.

Method

This study employed a quantitative approach with a pre-experimental one-group pretest-posttest design. The design involved one group of students measured before and after the implementation of Science, Technology, Engineering, and Mathematics (STEM)-based learning. Schematically, the research design can be represented as O1-X-O2, where O1 is the initial measurement (pretest), X is the STEM-based IPAS learning intervention on the Properties of Light, and O2 is the final measurement (posttest). The design was selected to accommodate the naturally established class condition (intact class), so the researcher did not randomly assign participants or create a new control group. This design enables the

researcher to describe and test changes in conceptual understanding scores within the same group after the learning sequence was implemented (Campbell & Stanley, 1963). Consequently, the findings are interpreted as within-group changes following the intervention and are not used to make absolute causal claims because external factors beyond the treatment could not be fully controlled.

The study was conducted at SD Negeri Sukamantri, Bandung Regency, West Java, in fifth-grade IPAS learning within Phase C of the Merdeka Curriculum. The target population was fifth-grade elementary school students studying the Properties of Light, while the accessible population was limited to fifth-grade students at the school where the study was conducted. Purposive sampling was used by considering the suitability of participants for the research objectives and the conditions of learning implementation. The sampling criteria included: students were actively enrolled in fifth grade; the class was studying the IPAS topic of the Properties of Light; the learning schedule allowed the complete sequence of pretest, intervention, and posttest to be conducted; and students participated in the research activities in accordance with the established procedures. Based on these criteria, one class was selected as the research group and all students in that class were included, resulting in a final analyzed sample of 35 students. The use of one intact class was maintained so that learning took place in a natural classroom context without altering the school's regular instructional structure.

Variables and Operational Definitions

The treatment variable in this study was STEM-based IPAS learning, defined as a sequence of learning activities integrating Science, Technology, Engineering, and Mathematics in the investigation of light phenomena and the completion of a simple engineering task. The Science component was implemented through observations and experiments on the properties of light; Technology through the use of simple tools and materials to support observations of optical phenomena; Engineering through activities to design, construct, test, and improve a simple periscope; and Mathematics through measuring material dimensions and applying angle concepts to mirror placement. The response variable was conceptual understanding of the Properties of Light. Conceptual understanding was operationalized as students' ability to interpret, classify, explain, infer, compare, summarize, and exemplify, in accordance with the cognitive process category of understanding in the taxonomy. Conceptual understanding scores were obtained from written tests administered before and after STEM learning and were then converted to the assessment scale used in the study.

Research Instruments

The research instruments consisted of measurement instruments and learning materials. The measurement instrument was a written cognitive test consisting of 10 essay questions. The ten items were developed to represent seven indicators of conceptual understanding: interpreting, classifying, explaining, inferring, comparing, summarizing, and exemplifying. The essay format was selected so that students' abilities were assessed not only through recognition of correct answers, but also through their ability to provide reasons, connect phenomena with concepts, construct explanations, and express their understanding in their own words. The test was administered as a pretest to obtain an overview of initial understanding and as a posttest to obtain an overview of understanding after the STEM learning sequence. The learning materials consisted of a teaching module, learning materials, and Student Worksheets (LKPD) containing investigations of the Properties of Light and simple periscope engineering activities. These materials were used to maintain alignment

among learning objectives, STEM activities, and the conceptual understanding indicators being evaluated.

Instrument Validity and Reliability

The test instrument was piloted with 23 respondents to evaluate item quality. The empirical validity of each item was analyzed using the Pearson Product-Moment correlation at a 5% significance level. With 23 pilot-test respondents, the degrees of freedom were df = 21 and the critical r value reported in the study was 0,413. The results of the empirical validity test for each item are presented in Table 1.

***Table 1**. Empirical Validity Test Results for the Conceptual Understanding Instrument*

Item	Calculated r	Critical r	Decision	Validity Category
S1	0,640	0,413	Valid	High
S2	0,604	0,413	Valid	High
S3	0,548	0,413	Valid	Moderate
S4	0,511	0,413	Valid	Moderate
S5	0,645	0,413	Valid	High
S6	0,508	0,413	Valid	Moderate
S7	0,561	0,413	Valid	Moderate
S8	0,498	0,413	Valid	Moderate
S9	0,537	0,413	Valid	Moderate
S10	0,462	0,413	Valid	Moderate

As shown in Table 1, the correlation coefficients for all items ranged from 0,462-0,645 and were all greater than the critical r value of 0,413. Therefore, all 10 items met the empirical validity criteria and were retained in the final instrument. Based on the classification used in the study, items S1, S2, and S5 were categorized as having high validity, whereas S3, S4, S6, S7, S8, S9, and S10 were categorized as moderate. The internal consistency of the instrument was evaluated using Cronbach's Alpha. The results of the instrument reliability test are presented in Table 2.

***Table 2.** Reliability Test Results for the Conceptual Understanding Instrument*

Number of Items	Cronbach's Alpha	Reference Value	Decision
10	0,744	0,60	Reliable

As shown in Table 2, the Cronbach's Alpha value of 0,744 was higher than the reference value of 0,60 used in the study. Therefore, the instrument was considered to have adequate internal consistency and could be used to measure conceptual understanding in the main data collection.

Research Procedure and Implementation of STEM Learning

The study was conducted through preparation, initial measurement, implementation of STEM learning, final measurement, and data analysis. The preparation stage included identifying learning problems, reviewing relevant literature, developing test instruments and learning materials, selecting the research class, obtaining formal permissions, and piloting the instrument to ensure its validity and reliability. Before the intervention, students completed a pretest consisting of 10 essay questions to measure their initial understanding of the Properties of Light. STEM learning then began with a contextual problem explored through learning materials and worksheets (LKPD), followed by collaborative investigation. 1). Science was implemented through experiments on reflection, refraction, the ability of light to pass through transparent objects, and light dispersion, in which students observed, recorded, compared results, and drew conclusions based on evidence.

2). Technology was implemented through the use of simple tools and materials, such as light sources, mirrors, transparent materials, water, and other relevant practical equipment, as means for observing and testing light concepts in accordance with the facilities available at the school. 3). Engineering was integrated through group activities to design and construct a simple periscope, beginning with identifying material requirements, preparing sketches and work steps, assembling and testing the product, and improving the design when the test results did not meet expectations. The process followed an iterative Engineering Design Process: identifying the problem, designing a solution, creating a prototype, testing, evaluating, and refining the design. 4). Mathematics was implemented through measuring materials and periscope dimensions and considering mirror-placement angles so that light reflection functioned as intended. After the entire learning sequence was completed, students took a posttest using the same measurement scope. Each student's pretest and posttest scores were then paired in the analysis, while achievement was also summarized according to the seven indicators of conceptual understanding to describe changes in more specific cognitive aspects.

Data Collection and Analysis Techniques

The primary data consisted of conceptual understanding scores obtained from written tests administered at two measurement points. The pretest was administered before STEM learning and the posttest after the intervention was completed. Paired measurements allowed each student's posttest score to be compared with the same student's pretest score. In addition to total scores, the percentage achievement for each conceptual understanding indicator was calculated to provide a more detailed description of the development of interpreting, classifying, explaining, inferring, comparing, summarizing, and exemplifying abilities. All collected data were checked for completeness before being analyzed using Statistical Package for the Social Sciences (SPSS) version 27.

Data analysis included descriptive and inferential statistics. Descriptive statistics were used to characterize pretest and posttest scores in terms of the number of participants, minimum, maximum, mean, standard deviation, and skewness coefficient. Percentage achievement for each conceptual understanding indicator was also calculated to compare patterns before and after learning. Data distributions were examined using the Shapiro-Wilk test because the sample size was relatively limited. In this article, the normality results were treated as information about the shape of the data distribution, whereas changes in paired scores were tested using the nonparametric Wilcoxon Signed-Rank Test. This approach avoids dependence of the inferential analysis on the normality assumption and is appropriate for comparing two measurements obtained from the same participants.

The inferential hypotheses were formulated as H0: there is no difference in the distribution of conceptual understanding scores between the pretest and posttest, and H1: there is a difference in the distribution of conceptual understanding scores between the pretest and posttest. Statistical decisions used a 5% significance level ($\alpha = 0,05$). Wilcoxon significance in this article is reported using the two-sided exact significance when available in the software output. In addition to the p-value, an effect size was calculated so that the results indicate not only whether the change was statistically significant but also the relative magnitude of the change. N-Gain analysis was used as an additional descriptive measure to describe the relative improvement in each student's score compared with the maximum possible improvement remaining from the initial score. The classification used in the study followed the criteria (2024): $g \geq 0,70$ was categorized as high, $0,30 \leq g < 0,70$ as moderate,

and g < 0,30 as low. In interpreting the results, N-Gain was used as supporting information on the degree of improvement, whereas inferential conclusions regarding score differences were based on the Wilcoxon Signed-Rank Test and supplemented by the effect size (Haslinar et al., 2022). Before the main data collection, the researcher obtained formal permissions from the school and related parties as documented in the research report. The activities were adjusted to the school's learning schedule so that the pretest, STEM learning sequence, and posttest could be conducted without fundamentally changing the classroom structure. These permissions provided the administrative basis for conducting data collection in the research class.

Result

Students' Conceptual Understanding Through STEM Learning

The presentation of the research results first focuses on changes in students' conceptual understanding scores before and after STEM learning. A total of 35 students completed the entire measurement sequence, so the numbers of pretest and posttest observations were the same. Descriptive statistics indicate a consistent shift toward higher scores at the final measurement. A summary of the pretest and posttest statistics is presented in Table 3.

Table 3. *Descriptive Statistics of Pretest and Posttest Scores*

Measurement	N	Minimum	Maximum	Mean	Standard Deviation	Skewness	Mean Difference
Pretest	35	38,00	60,00	46,57	6,57	0,608	-
Posttest	35	70,00	95,00	85,14	6,74	-0,299	38,57

As shown in Table 3, the mean conceptual understanding score increased from 46,57 on the pretest to 85,14 on the posttest, representing an average increase of 38,57 points. The change was also evident in the lower and upper bounds of the score distribution. The minimum score increased from 38,00 to 70,00, while the maximum increased from 60,00 to 95,00. The standard deviation remained relatively stable, at 6,57 on the pretest and 6,74 on the posttest. Thus, the increase in the mean was not accompanied by a substantial change in score variability among students. The skewness coefficient changed from 0,608 to -0,299. These values are used as descriptive information about the shape of the distribution and are not positioned as a substitute for statistical assumption testing.

In addition to total scores, the results were analyzed according to seven indicators of conceptual understanding: interpreting, classifying, explaining, inferring, comparing, summarizing, and exemplifying. Indicator-level presentation was intended to identify which cognitive aspects showed the greatest changes and which remained relatively lower after learning. Percentage achievement for each indicator is presented in Table 4.

Table 4. *Achievement on the Seven Indicators of Conceptual Understanding*

Conceptual Understanding Indicator	Pretest (%)	Posttest (%)
Interpreting	49	84
Classifying	48	88
Explaining	44	84
Inferring	45	82
Comparing	47	86
Summarizing	46	85
Exemplifying	45	86

All indicators showed higher posttest percentages than pretest percentages. The highest posttest achievement was in classifying at 88%, followed by comparing and exemplifying at

86% each, summarizing at 85%, interpreting and explaining at 84% each, and inferring at 82%. In terms of the magnitude of change, exemplifying showed the largest increase, at 41 percentage points. Classifying and explaining each increased by 40 points, comparing and summarizing by 39 points each, inferring by 37 points, and interpreting by 35 points. Thus, no indicator decreased at the final measurement. These data also show that improvement was not limited to a single type of cognitive process but was distributed across all measured indicators.

To assess the direction of score changes at the individual level and test pretest-posttest differences inferentially, the Wilcoxon Signed-Rank Test was used. The rank results showed that all students obtained higher posttest scores than pretest scores. No student showed a decrease or an unchanged score. A summary of the ranks and test statistics is presented in Table 5.

Table 5. *Wilcoxon Signed-Rank Test Results and Effect Size*

Component	Statistic	Value
Ranks	Negative Ranks (N)	0
	Positive Ranks (N)	35
	Ties (N)	0
	Mean Positive Rank	18,00
	Sum of Positive Ranks	630,00
Wilcoxon Test	Z	-5,163
Wilcoxon Test	Exact Sig. (2-tailed)	< 0,001
Effect Size	r = |Z| / √N	0,873

Table 5 shows 35 positive ranks, with no negative ranks and no ties. The mean rank for positive changes was 18,00, with a sum of ranks of 630,00. The Wilcoxon Signed-Rank Test yielded Z = -5,163 with a two-sided exact p-value < 0,001. At the 5% significance level, this result indicates a significant difference between conceptual understanding scores before and after STEM learning. The effect size calculated using $r = |Z|/\sqrt{N}$ yielded a value of 0,873. This value indicates a strong magnitude of pretest-posttest change in the group studied. This inferential result should be interpreted as a within-group change because the study did not include a comparison group.

N-Gain Analysis

N-Gain was used as an additional descriptive measure to describe students' relative score improvement in relation to the maximum possible improvement remaining from the pretest score. N-Gain statistics are presented in Table 6.

Table 6. *Descriptive Statistics of N-Gain*

N-Gain Statistic	Value
N	35
Mean N-Gain	0,7156
Standard Deviation	0,14154
Minimum	0,40
Maximum	0,92
Mean N-Gain (%)	71,56%

The mean N-Gain was 0,7156 or 71,56%. Based on the criteria used in the study, this mean was classified as high. Individual N-Gain values ranged from 0,40 to 0,92, with a standard deviation of 0,14154. This range indicates that the relative improvement among students was not identical, although the aggregate mean improvement was in the high category. Because N-Gain is a descriptive measure, it was interpreted as a complement to the

Wilcoxon results and effect size rather than as a sole basis for making causal claims. Overall, the research data show four main patterns. First, the mean score increased by 38,57 points, accompanied by increases in the minimum and maximum scores. Second, all seven indicators of conceptual understanding improved, with changes ranging from 35 to 41 percentage points. Third, all 35 students were in the positive ranks in the Wilcoxon analysis, with no decreased or unchanged scores. Fourth, the pretest-posttest difference was statistically significant ($Z = -5,163$; exact $p < 0,001$) with an effect size of $r = 0,873$, while the mean N-Gain was 0,7156. These findings provide the basis for discussing the learning mechanisms, connections with previous studies, and interpretive limitations presented in the following section.

Discussion

The results show a clear change in conceptual understanding of the Properties of Light after students participated in STEM learning. The mean score increased from 46,57 to 85,14, all students obtained higher posttest scores, and the change was significant based on the Wilcoxon Signed-Rank Test with an effect size of $r = 0,873$. The consistency among descriptive statistics, the direction of individual changes, inferential test results, and N-Gain indicates that the observed change was not merely the result of an increase in the mean driven by only a few students. All participants moved in the same direction, while the pretest and posttest standard deviations were relatively similar. This pattern shows that improvement occurred throughout the group with relatively stable variability in achievement.

Substantively, this change can be understood from the characteristics of the learning process, which gave students opportunities to use light concepts in activities that could be observed and tested. Before the intervention, the preliminary study indicated a gap between students' ability to name phenomena and their ability to explain the underlying mechanisms. In STEM learning, the concepts of reflection, refraction, propagation, the ability of light to pass through objects, and dispersion were not presented only verbally, but were embedded in observation, experimentation, discussion, and periscope engineering activities. This shift from receiving information to using information is important because conceptual understanding requires students to organize and connect knowledge rather than merely remember terms.

These findings are consistent with the previous studied, who reported improved understanding of light concepts through STEM-based guided inquiry, and the another studied who showed that a STEAM approach can strengthen elementary students' conceptual understanding of scientific phenomena (Nasir et al., 2022; Corrigan et al., 2025). However, the similarity in the direction of findings does not mean that the design strength of this study is equivalent to that of studies using comparison groups. In the present study, the absence of a control group limits the ability to separate changes due to STEM learning from other possible influences. Therefore, the results are more appropriately understood as strong evidence of within-group change following the intervention rather than as a causal estimate completely free from external factors.

A more detailed examination of the indicator-level analysis provides richer information than total scores alone. All indicators improved, but the magnitude of change differed. Exemplifying showed the largest increase, at 41 percentage points, while classifying and explaining each increased by 40 points. Comparing and summarizing each increased by 39 points, inferring by 37 points, and interpreting by 35 points. These differences indicate that the learning process did not affect every cognitive process in an identical pattern.

High achievement in classifying and exemplifying can be related to the nature of activities that repeatedly required students to recognize the properties of objects and optical phenomena concretely. When students tested whether light could pass through particular materials, observed differences in light behavior, or identified examples of reflection and refraction around them, they obtained an empirical basis for grouping objects and generating new examples. This is consistent with the previous studied, who emphasized the importance of example-classification activities in forming conceptual categories. Improvement in exemplifying also indicates that students became more capable of transferring concepts from learning situations to other relevant phenomena, a characteristic of understanding that is more meaningful than memorizing definitions (Steininger et al., 2022).

The explaining indicator increased by 40 percentage points. This change is important because explaining requires students to construct cause-and-effect relationships rather than merely recognize phenomena. During learning, students did not stop at observing that a pencil in water appeared displaced or that light was reflected by a mirror. They were guided to connect these observations with the concepts of refraction and reflection. The previous studied showed that the process of producing representations and explanations of scientific phenomena is related to the development of conceptual understanding (McLure et al., 2022). Discussion activities after the experiments may have provided students with opportunities to examine the adequacy of their explanations against the evidence obtained.

Inferring had the lowest posttest achievement among the seven indicators, at 82%, although it still increased by 37 percentage points. This pattern can be understood because inferring requires the integration of several pieces of information into a defensible generalization. Students must identify patterns, distinguish important data from supplementary information, and generate conclusions that are consistent with the evidence. The position inductive reasoning and scientific reasoning as important abilities in STEM achievement (Vo & Csapó, 2023). Thus, the relatively lower achievement on this indicator does not indicate learning failure, but suggests that future activities should allocate more emphasis to evidence analysis and conclusion building.

The improvement pattern can also be explained through the relationship among the four STEM components used in the intervention. Science provided the conceptual foundation through investigations of reflection, refraction, light propagation, the ability of light to pass through materials, and dispersion. These activities gave students experience in comparing predictions with actual results. When observations did not match their initial expectations, students had opportunities to revise their mental representations based on evidence. Such empirical experiences are important for the topic of light, which is prone to being understood through everyday intuitions that may not align with scientific explanations.

Technology functioned as a means of conducting and clarifying observations. Simple equipment such as light sources, mirrors, transparent materials, and supporting experimental tools did not merely serve as aids, but enabled abstract concepts to become observable. In the elementary school context, technology does not always have to take the form of digital devices. The use of tools aligned with learning objectives and capable of helping students obtain evidence is also an important component of STEM integration.

Engineering was an important distinguishing component because students did not only conduct separate experiments but also used their conceptual understanding to produce a simple periscope. The engineering process included identifying needs, developing a design, selecting materials, constructing a prototype, testing, evaluating, and improving the design.

The previous studied explained that engineering design among elementary school students is an iterative process in which students develop solutions through testing and revision (Sung & Kelley, 2022). In this study, a periscope that did not function properly or produced an unexpected reflection could provide direct feedback that aspects of the design or understanding needed to be revised. Thus, the engineered product was not merely an end product, but a medium for using and evaluating scientific concepts.

Mathematics supported the engineering process through measurement of material dimensions, comparison of sizes, and determination of mirror orientation. Mathematics moved the concept of reflection beyond qualitative description by connecting it with the precision of component positioning within the device. This integration shows that the four disciplines did not operate as separate components but complemented one another in solving the problem. The benefits of integrated STEM are strongly influenced by the quality of interdisciplinary connections and the alignment of activities with the intended outcomes (Le et al., 2023). The findings of this study support that view because improved understanding occurred alongside activities that explicitly connected concepts, observations, design, and measurement.

In relation to previous studies, these findings strengthen evidence that STEM learning can be used to support science learning in elementary schools, although the contribution of this study needs to be positioned specifically. The previous studied reported benefits of STEM combined with Project-Based Learning for creativity and science conceptual understanding (Yulaikah & Rahayu, 2022). The implemented STEM in fifth-grade electricity learning (Helga et al., 2024). The focused on the development of STEM-based IPAS teaching modules (Puspitasari et al., 2024). The previous studied whereas developed STEM worksheets on periscope material. Therefore, neither the use of STEM nor the periscope project constitutes novelty by itself (Mardita et al., 2022).

The contribution of this study lies in two aspects. First, the intervention placed investigations of the Properties of Light and periscope engineering within the context of Phase C IPAS learning so that optical concepts were used directly in a task with a real function. Second, the results were not reported only as a single total score but were mapped across seven indicators of conceptual understanding. This mapping yielded richer diagnostic information: students showed relatively strong achievement in classifying and exemplifying, while inferring remained the indicator with the lowest final achievement. This information has practical value because teachers can determine follow-up activities based on aspects of understanding that still require reinforcement.

The effect size of r = 0,873 and the mean N-Gain of 0,7156 indicate a large magnitude of within-group change. Nevertheless, these two measures do not eliminate the limitations of the design. The effect size in a one-group pretest-posttest design reflects the magnitude of the observed change rather than a net causal effect after all alternative explanations have been controlled. Therefore, future research should use a comparison group, include more than one class or school, and, where possible, incorporate follow-up measurements to determine whether understanding is retained after the intervention ends. Such designs would allow the contribution of STEM to score changes to be distinguished more effectively from test-repetition effects, maturation, or classroom conditions.

Although the study showed consistent improvement, the findings should be interpreted in light of several limitations. The one-group pretest-posttest design without a comparison group limits causal inference, while the sample of only 35 students from one class limits generalizability. Implementation time and equipment availability may also have influenced the

intensity of students' learning experiences during the engineering phase. In practice, STEM learning can still be considered as an alternative approach to IPAS learning when experiments, design processes, and scientific concepts are explicitly connected and sufficient time is provided for product testing and improvement. Future studies are recommended to use comparison groups, involve more classes or schools, and add retention measurements and misconception diagnostic instruments to provide stronger evidence regarding the contribution of STEM learning.

Conclusion

This study shows that fifth-grade students' conceptual understanding of the Properties of Light improved consistently after the implementation of STEM learning. The mean score increased from 46,57 on the pretest to 85,14 on the posttest, an increase of 38,57 points. All 35 students obtained higher posttest scores than pretest scores, with no negative ranks or ties. The Wilcoxon Signed-Rank Test showed a significant difference ($Z = -5{,}163$; two-sided exact $p < 0{,}001$) with an effect size of $r = 0{,}873$, while the mean N-Gain was 0,7156 or 71,56%, classified as high. Improvement also occurred across all seven indicators of conceptual understanding, with changes ranging from 35 to 41 percentage points.

These findings indicate that learning integrating scientific investigation, the use of simple technology, engineering processes, and mathematical measurement has the potential to support students in building more meaningful conceptual understanding. Nevertheless, the one-group pretest-posttest design without a comparison group limits the strength of causal inference and the generalizability of the findings. Therefore, future research should use comparison groups, involve more classes or schools, and consider retention measurements and misconception diagnostic instruments to obtain stronger evidence regarding the contribution of STEM learning.

Acknowledgment

-

Reference

Belousova, A. K., Tushnova, Y. A., Maslyaeva, N. S., Khachaturyan, N. N., & Suroedova, E. A. (2026). Misconceptions of primary school students about light phenomena. *International Journal of Cognitive Research in Science, Engineering and Education (IJCRSEE)*, 14(1), 23–36. https://doi.org/10.23947/2334-8496-2026-14-1-023-036

Campbell, D. T., & Stanley, J. C. (1963). *Experimental and quasi-experimental designs for research*. Houghton Mifflin.

Corrigan, M. W., Wong, J. T., Grove, D., Andersen, S., & Hughes, B. S. (2025). Enhancing elementary students' conceptual understandings of scientific phenomena: The impact of STEAM-first and STEM-first approaches. *Science Education*, 109(5), 1336–1364. https://doi.org/10.1002/sce.21942

Buabeng, I., & Amo-Darko, B. (2025). Curriculum reforms without foundation: The effects of inadequate preparation in curriculum reforms on Ghanaian teachers and the education system. *Curriculum Perspectives*, *45*(2), 133-147.

Subramaniam, R. C., Morphew, J. W., Rebello, C. M., & Rebello, N. S. (2025). Presenting a STEM ways of thinking framework for engineering design-based physics problems. *Physical Review Physics Education Research*, *21*(1), 010122.

Haslinar, H., Daud, F., & Syamsiah, S. (2022). The Effect of the Guided Discovery Learning Model on Students' Scientific Attitudes and Learning Outcomes in Grade X Biology. *Biology Teaching and Learning, 5*(1). DOI: https://doi.org/10.35580/btl.v5i1.33910

Helga, M., Untari, M. F. A., & Mulyani. (2024). The Application of a STEM Approach in Teaching Electric Circuits and Power Generation to Fifth-Grade Elementary School Students. *Jurnal Basicedu*, 8(2), 1068–1077. https://doi.org/10.31004/basicedu.v8i2.7243

Irsan. (2021Implementation of Scientific Literacy in Science Learning in Elementary Schools. *Jurnal Basicedu*, 5(6), 5631–5639. https://doi.org/10.31004/basicedu.v5i6.1682

Le, H. C., Nguyen, V. H., & Nguyen, T. L. (2023). Integrated STEM approaches and associated outcomes of K–12 student learning: A systematic review. *Education Sciences*, 13(3), 297. https://doi.org/10.3390/educsci13030297

Mardita, M., Alim, J. A., Hermita, N., & Wijaya, T. T. (2022). Development of MIKiR-Based STEM Worksheets on the Topic of Periscopes. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika*, 11(1), 398–406. https://doi.org/10.24127/ajpm.v11i1.4676

McLure, F., Won, M., & Treagust, D. F. (2022). Analysis of students' diagrams explaining scientific phenomena. *Research in Science Education*, 52(4), 1225–1241. https://doi.org/10.1007/s11165-021-10004-y

Nasir, M., Cari, C., Sunarno, W., & Rahmawati, F. (2022). The effect of STEM-based guided inquiry on light concept understanding and scientific explanation. *Eurasia Journal of Mathematics, Science and Technology Education*, 18(11), em2175. https://doi.org/10.29333/ejmste/12499

Nurfiyani, Y., Putra, M. J. A., & Hermita, N. (2020). Analysis of Misconceptions of Grade V Elementary School Students on the Concept of the Properties of Light. *Journal of Natural Science and Integration*, 3(1), 77–86. https://doi.org/10.24014/jnsi.v3i1.9303

OECD. (2023). PISA 2022 results (Volume I and II)—Country notes: Indonesia. OECD.

Prasetyo, D., Marianti, A., & Alimah, S. (2021). Improvement of students' science literacy skills using STEM-based e-modules. *Journal of Innovative Science Education*, 10(2), 216–221. https://doi.org/10.15294/jise.v9i3.43539

Puspitasari, J. F., Patonah, S., & Sukamto. (2024). Development of STEM-Based IPAS Teaching Modules to Realize the Basic Scientific Thinking Skills of Elementary School Students. *Jurnal Basicedu,* 8(2), 1235–1245. https://doi.org/10.31004/basicedu.v8i2.7319

Steininger, T. M., Wittwer, J., & Voss, T. (2022). Classifying examples is more effective for learning relational categories than reading or generating examples. *Instructional Science*, 50, 771–788. https://doi.org/10.1007/s11251-022-09584-7

Sung, E., & Kelley, T. R. (2023). Elementary students' engineering design process: How young students solve engineering problems. *International Journal of Science and*

Mathematics Education, 21(5), 1615–1638. https://doi.org/10.1007/s10763-022-10317-y

Tampubolon, L. W. S., & Megalina, Y. (2025). Development of Authentic Assessment Instruments to Measure Students' Critical Thinking Skills in Science Learning on Temperature and Heat (Case Study of Grade XI Students of SMAN 2 Medan). *Jurnal Pelita: Jurnal Pembelajaran IPA Terpadu*, *5*(2), 592–600. https://doi.org/10.54065/pelita.5.2.2025.976

Tohani, E., & Aulia, I. (2022). Effects of 21st century learning on the development of critical thinking, creativity, communication, and collaboration skills. *Journal of Nonformal Education*, 8(1). https://doi.org/10.15294/jne.v8i1.33334

Vo, D. V., & Csapó, B. (2023). Exploring inductive reasoning, scientific reasoning and science motivation, and their role in predicting STEM achievement across grade levels. *International Journal of Science and Mathematics Education*, 21, 2375–2398. https://doi.org/10.1007/s10763-022-10349-4

Yulaikah, I., Rahayu, S., & Parlan. (2022). Effectiveness of STEM Learning with the PjBL Model on Creativity and Conceptual Understanding of Science among Elementary School Students. *Jurnal Pendidikan: Teori, Penelitian, dan Pengembangan*, 7(6), 223–229. https://doi.org/10.17977/2502-471X.2477

Yusmar, F., & Fadilah, R. E. (2023). Effectiveness of STEM Learning with the PjBL Model on Creativity and Conceptual Understanding of Science among Elementary School Students. *LENSA (Lentera Sains): Jurnal Pendidikan IPA*, 13(1), 11–19. https://doi.org/10.24929/lensa.v13i1.283