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Exploring Misconceptions of Light and Shadow Formation among Senior High School Students: A Qualitative Study in Physics Education

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Abstract: *This study explores senior high school students' misconceptions of light and shadow formation within the context of physics education. Despite being a fundamental concept in optics, many students continue to experience difficulties in understanding the principles of light propagation, the rectilinear nature of light, and the conditions required for shadow formation. This research employed a qualitative exploratory design involving 32 students from Grade X and XI science classes in Central Java, Indonesia. Data were collected through diagnostic tests and semi-structured interviews, which allowed in-depth identification of alternative conceptions. The analysis revealed three dominant categories of misconceptions: (1) perceiving light as a substance that "flows" from the source, (2) assuming that shadows are independent objects rather than regions of blocked light, and (3) misunderstanding the relationship between light intensity, distance, and shadow clarity. These findings confirm that students often rely on intuitive reasoning based on everyday experiences rather than scientific explanations. The discussion highlights the implications for physics instruction, particularly the need for teaching strategies that incorporate conceptual change models and inquiry-based learning to address students' alternative frameworks. The study concludes that addressing misconceptions in optics requires not only emphasizing correct scientific principles but also engaging students in reflective and interactive learning processes that directly confront their prior conceptions.*

Keywords: *light, misconceptions, physics education, qualitative study, shadow*

Mengeksplorasi Miskonsepsi Siswa SMA tentang Pembentukan Cahaya dan Bayangan: Studi Kualitatif dalam Pendidikan Fisika

Abstrak: Penelitian ini mengeksplorasi miskonsepsi siswa sekolah menengah atas mengenai pembentukan cahaya dan bayangan dalam konteks pendidikan fisika. Meskipun merupakan konsep fundamental dalam optika, banyak siswa masih mengalami kesulitan dalam memahami prinsip perambatan cahaya, sifat garis lurus cahaya, serta kondisi terbentuknya bayangan. Penelitian ini menggunakan desain kualitatif eksploratori dengan melibatkan 32 siswa kelas X dan XI dari sekolah menengah atas di Jawa Tengah, Indonesia. Data dikumpulkan melalui tes diagnostik dan wawancara semi-terstruktur yang memungkinkan identifikasi mendalam terhadap konsepsi alternatif siswa. Analisis mengungkap tiga kategori miskonsepsi utama: (1) menganggap cahaya sebagai zat yang "mengalir" dari sumber, (2) mengasumsikan bahwa bayangan adalah objek independen, bukan daerah yang tidak terkena cahaya, dan (3) salah memahami hubungan antara intensitas cahaya, jarak, dan ketajaman bayangan. Temuan ini menegaskan bahwa siswa lebih sering mengandalkan penalaran intuitif berbasis pengalaman sehari-hari daripada penjelasan ilmiah. Diskusi menyoroti implikasi bagi pembelajaran fisika, khususnya kebutuhan strategi pengajaran yang memasukkan model perubahan konseptual dan pembelajaran berbasis inkuiri untuk mengatasi kerangka alternatif siswa. Kesimpulannya, upaya mengatasi miskonsepsi optika tidak hanya menekankan prinsip ilmiah yang benar, tetapi juga melibatkan siswa dalam proses belajar reflektif dan interaktif yang secara langsung menghadapkan mereka pada konsepsi awal yang keliru.

Kata kunci: bayangan, cahaya, miskonsepsi, pendidikan fisika, studi kualitatif

INTRODUCTION

Misconceptions are a persistent challenge in physics education, particularly in optics where students often treat shadows as “objects” or assume that vision involves light emitted from the eyes. Such alternative conceptions are resistant to change because they are supported by everyday experiences. Importantly, the issue of misconceptions is not limited to optics. A recent study in Kasuari: Physics Education Journal emphasized that even in abstract topics such as alternating current (AC) circuits, students still exhibited deep-seated misconceptions that obstructed meaningful learning. This finding highlights that addressing misconceptions is a widespread priority across physics domains and not only within the study of light and shadows (Pratama, 2025).

Optics is a foundational part of physics education, yet Indonesian students still face persistent conceptual barriers. PISA 2022 shows only ~34% of Indonesian 15-year-olds reach Level 2+ in science (OECD average: 76%), underscoring the need for instruction that targets deep understanding rather than procedural recall (OECD, 2023). In policy terms, Kurikulum Merdeka promotes inquiry-rich, formative-assessment practices—conditions that are well suited to surfacing and restructuring alternative conceptions in physics.

Within optics, light and shadow formation is a fertile domain for misconceptions: students may treat light as a “substance,” reify shadows as objects (rather than regions where light is blocked), or misread geometric factors (source type/size, object–screen distance) behind shadow size and sharpness; such ideas often resist instruction and also appear among pre-service teachers (Kaltakci-Gurel et al., 2017; Métioui, 2023). In the Indonesian context, recent reviews and diagnostics continue to document difficulties around light sources, ray diagrams, and rectilinear propagation—suggesting that even exposure to the topic does not guarantee conceptual change (Putri et al., 2024; Soeharto & Csapó, 2022).

Methodologically, multi-tier diagnostic instruments have advanced rapidly and are now common in Indonesia. A two-tier light concept test developed with IRT provides robust validity evidence (Nasir et al., 2023), while four-tier optics instruments and modified formats for geometrical optics have been trialed to distinguish lack of knowledge, low confidence, and robust misconceptions (Bhakti et al., 2023; Kunaedi et al., 2024). Explorations of five-tier tests, though younger, further highlight feasibility for diagnosing misconception sources in geometrical optics (Salmadhia et al., 2021). Collectively, these tools enable fine-grained profiles of students’ alternative conceptions that can guide qualitative probing through interviews.

Despite diagnostic progress, qualitative accounts that trace how senior high-school students reason about umbra–penumbra and extended-source geometry remain limited. Indonesian and international reports point to persistent difficulty predicting shadow position/clarity and coordinating rectilinear-propagation with source–object–screen relations (Putri et al., 2024; Soeharto & Csapó, 2022). Addressing this gap calls for triangulating multi-tier tests with semi-structured interviews to map reasoning resources (perceptual heuristics, everyday experience, and school definitions) and how they play out in discrepant tasks (varying distances, multi-source scenarios).

On the pedagogy side, conceptual-change approaches remain central. A recent meta-analysis confirms refutation texts yield positive, moderate benefits for science learning across contexts (Schroeder & Kucera, 2022), and evidence from Indonesia shows cognitive-conflict-based learning (CCBL) improves conceptual understanding and remedies misconceptions (Mufit et al., 2023). Complementarily, inquiry-oriented designs report gains in engagement and higher-order thinking—and align with Kurikulum Merdeka emphases (Sapriati et al., 2024).

Research gap and aim. Building on this landscape, the present study provides curriculum-aligned, qualitative evidence on Indonesian senior high-school students' reasoning about light and shadow formation. We (1) characterize dominant and nuanced alternative conceptions involving rectilinear propagation, source geometry, and umbra/penumbra; (2) trace students' reasoning through interviews triangulated with multi-tier diagnostics; and (3) derive design principles for inquiry- and conflict-based lessons implementable under Kurikulum Merdeka.

THEORETICAL

Conceptual Understanding of Light and Shadow

In physics education, understanding light and shadow formation is central to the broader topic of geometrical optics. Scientifically, light is modeled as a ray that propagates in straight lines in homogeneous media, enabling explanations of reflection, refraction, and shadow formation (Tipler & Mosca, 2019). Shadows occur when an opaque object blocks incident rays, producing a dark region (umbra) and, with extended sources, a partial shadow (penumbra) (Hecht, 2017). These principles are critical benchmarks for scientific literacy, as emphasized in both the Indonesian Kurikulum Merdeka and international assessments such as PISA (OECD, 2023).

Misconceptions in Optics Education

Extensive research has shown that students frequently harbor alternative conceptions that conflict with scientific views. Common patterns include treating light as a substance that flows or emanates from the eye (Kaltakci-Gurel et al., 2017), conceptualizing shadows as independent objects rather than regions of blocked light (Sujarwanto & Abdurrahman, 2021) and confusing brightness with shadow geometry (Syahrul et al., 2020). Misunderstandings about umbra and penumbra are particularly persistent, as students often perceive only a single homogeneous shadow region (Putri et al., 2024; Soeharto & Csapó, 2022). These misconceptions are consistent across different levels of education and even appear among pre-service physics teachers (Métioui, 2023).

Diagnostic Tools in Optics Misconceptions

In the past decade, the development of multi-tier diagnostic tests has become a major advancement. Two-tier tests combine answer and reasoning (Yusnia et al., 2020), four-tier instruments add confidence and error source measures (Negoro & Karina., 2019), and five-tier formats provide even deeper probing into misconceptions (Kunaedi et al., 2024; Mustofa et al., 2023). Such instruments allow teachers and researchers to differentiate between lack of knowledge, low confidence, and entrenched misconceptions. However, as (Nasir et al., 2023) note, diagnostic results must be supplemented with qualitative interviews to uncover the reasoning processes behind students' responses.

Conceptual Change and Instructional Approaches

Theoretical perspectives on conceptual change (Chi, 2008; Posner et al., 1982) argue that misconceptions are robust frameworks requiring active restructuring. Pedagogical approaches such as cognitive conflict (Mufit et al., 2023; Widiyatmoko et al., 2021) and refutation texts (Schroeder & Kucera, 2022) are grounded in this theory. Inquiry-based learning, promoted in Kurikulum Merdeka, is also consistent with constructivist principles, encouraging students to test predictions against evidence and revise their models (Rapi et al., 2022; Sapriati et al., 2024).

Relevance to the Present Study

Based on these theoretical perspectives, this study situates students' misconceptions of light and shadow within the constructivist paradigm, treating them not as isolated mistakes but as alternative mental models. By integrating diagnostic tools with qualitative interviews, the research seeks to uncover both the content of misconceptions and the reasoning patterns that sustain them. This provides a more complete theoretical grounding for designing instructional interventions aligned with conceptual change theory and the goals of Kurikulum Merdeka.

METHOD

Research Design

This study employed a qualitative exploratory design situated within the constructivist paradigm. The qualitative approach was selected because the aim was not to measure the prevalence of misconceptions quantitatively, but to explore in depth how senior high school students reason about light and shadow formation (Creswell & Poth, 2018). Data collection combined diagnostic testing and semi-structured interviews to ensure triangulation and strengthen validity.

Participants and Context

The participants were 36 students (20 from Grade X and 16 from Grade XI) enrolled in science-stream classes at a public senior high school in Central Java, Indonesia, during the 2024/2025 academic year. Students were selected using purposive sampling to represent variation in grade level and prior exposure to optics. The school has implemented the Kurikulum Merdeka, making it a suitable context for examining conceptual understanding within the current curriculum framework.

Instruments

The study employed two main instruments. The first was a four-tier diagnostic test on light and shadow formation, adapted from Putri et al. (2024) and Negoro & Karina (2019). Each item required students to select an answer, provide a reason, indicate their confidence level, and specify the perceived source of their error, if any. For example, one item asked: "A small opaque object is placed in front of an extended light source. Students are asked to predict the shadow observed on the screen and explain the umbra–penumbra region." The second instrument was a semi-structured interview protocol administered to 12 selected students representing high, medium, and low diagnostic scores. The follow-up interviews included guiding questions such as "Can you explain what causes a shadow to be sharp or blurry?", "How would the shadow change if we used two light sources instead of one?", and "What do you think happens if the screen is moved farther away from the object?" Each interview lasted approximately 20–30 minutes, was audio-recorded, and transcribed verbatim.

Data Collection Procedures

The data collection procedures consisted of three main stages. First, the diagnostic test was administered to all 36 participants during their regular physics lessons. Second, the selection of interviewees was conducted based on their diagnostic profiles, including students who showed strong misconceptions, mixed reasoning, or near-scientific understanding. Finally, semi-structured interviews were carried out, focusing on students' reasoning processes and allowing probing of their explanations as well as the use of drawings and gestures.

Data Analysis

Data analysis followed the thematic coding approach (Braun & Clarke, 2021). First, diagnostic responses were categorized into scientifically accurate conceptions, partial conceptions, or misconceptions. Then, interview transcripts were coded inductively to identify themes such as "light-as-substance," "shadow-as-object," "geometry-based reasoning," and "mixed reasoning." Cross-case analysis compared Grade X and XI patterns. To ensure trustworthiness, triangulation was achieved by integrating test and interview data. Peer debriefing was conducted with two physics education researchers to refine coding categories. Member checking was implemented by returning interview summaries to participants for verification.

Ethical Considerations

All participants provided informed consent. School authorities approved the research, and anonymity was maintained by using pseudonyms in reporting.

RESULTS

Diagnostic Test Findings

The four-tier diagnostic test revealed several persistent misconceptions regarding light and shadow formation. Table 1 summarizes the categories, examples of student reasoning, and frequencies observed among the 36 participants.

Table 1. Categories of Students' Misconceptions on Light and Shadow Formation

No	Category of Misconception	Typical Student Statement	Frequency (n = 36)	%
1	Light as Substance (light is treated as a material that "flows" or "sticks" to objects)	"Light sticks to the object, that is why the shadow is formed behind it."	12	33.3
2	Shadow as Object (shadow is reified as an independent entity rather than blocked light)	"The shadow is an object that comes out when light hits the object."	10	27.8
3	Size Misconception (believing brighter light always produces larger shadows, ignoring distance and geometry)	"If the lamp is stronger, the shadow will be bigger even if the distance is the same."	8	22.2
4	Umbra/Penumbra Confusion (failure to distinguish sharp umbra vs. blurred penumbra from extended sources)	"There is only one type of shadow; it is always black and has the same sharpness."	14	38.9
5	Multiple Light Source Difficulty (inability to predict overlapping shadows from two lamps)	"Two lamps will just make the shadow darker, not produce two overlapping ones."	9	25.0

Note: Many students exhibited more than one misconception simultaneously.

Overall, the most prevalent difficulties were with umbra/penumbra reasoning (38.9%) and the light-as-substance model (33.3%). This indicates that fundamental principles of rectilinear propagation and source geometry remain poorly internalized.

Detailed Analysis of Misconceptions

The analysis revealed several recurring misconceptions among students. About one-third of students (33.3%) held the belief that light is a kind of material fluid that flows and accumulates on surfaces. For instance, a Grade X student explained, *"Light sticks to the object, that is why the shadow appears behind it"* (Student X7). This reasoning mirrors what Métioui (2023) found among pre-service teachers, where light was described as a material that adheres rather than as a propagation of energy. Such conceptions are grounded in everyday phenomenology, as students often perceive light beams from car headlights or flashlights as tangible, flowing "stuff."

Another misconception, held by approximately 28% of students, was that shadows are independent entities, as if they were objects produced by light. One Grade XI student stated, *"The shadow comes out of the object when light shines on it"* (Student XI3). This idea resonates with findings by Sujarwanto and Abdurrahman (2021), who documented similar reasoning in Indonesian classrooms. Such reasoning suggests that students tend to anthropomorphize physical phenomena—reifying shadows into "things" rather than understanding them as regions of blocked light.

The most common difficulty, reported by 38.9% of students, was the failure to differentiate umbra and penumbra. When presented with an extended source, one student insisted, *"There is only one type of shadow. It is always black and has the same sharpness"* (Student X2). This finding is particularly significant because umbra/penumbra reasoning is directly assessed in PISA-style tasks (OECD, 2023). Putri et al. (2024) similarly reported that students often predict only a single dark region, even when experimental setups produce multiple gradients.

Another misconception concerned the relationship between source brightness and shadow size. Nearly one-fourth of students (22.2%) believed stronger light sources create larger shadows. For example, a student noted, *"If the lamp is stronger, the shadow will be bigger even if the distance is the same"* (Student XI5). This reflects a confusion between intensity (brightness) and geometry (distance, size, angle). Similar findings are reported by Nasir et al. (2023), showing that students often fail to separate photometric variables from geometric optics.

Finally, difficulties also emerged when students considered multiple light sources. With two lamps, 25% of students predicted only *"one darker shadow."* A Grade XI student commented, *"Two lamps will just make the shadow darker, not make two different ones"* (Student XI9). This misconception illustrates the cognitive load involved in coordinating overlapping umbra–penumbra regions. Soeharto and Csapó (2022) noted that multiple-source problems often produce higher misconception rates, as students tend to default to simpler, linear reasoning.

Grade-Level Comparison

The comparison across grade levels reveals important differences in students' misconceptions. Grade X students were more likely to exhibit the light-as-substance and shadow-as-object misconceptions, often providing everyday explanations without the support of diagrams. In contrast, Grade XI students more frequently attempted to use ray diagrams, but they still showed confusion when differentiating between umbra and penumbra as well as in distinguishing intensity from geometry. This progression suggests that while instruction improves vocabulary and diagram use, deeper conceptual integration remains incomplete—echoing findings by (Kunaedi et al., 2024) on diagnostic test results across grade levels.

Interview Findings

Semi-structured interviews provided deeper insight into students' reasoning processes. Several students explained shadows using analogies to paint or dust, suggesting that "light sticks on surfaces." This reflects everyday-experience reasoning and echoes the substance model also reported by Métioui (2023). Some Grade XI students demonstrated partial geometry reasoning, as they were able to draw ray diagrams correctly but still claimed that "a stronger lamp makes sharper shadows," indicating partial understanding while failing to integrate intensity and geometry concepts. Another difficulty arose with multiple-source confusion: when asked about two lamps, many students insisted there would only be "one darker shadow," showing that they struggled to mentally coordinate overlapping umbra and penumbra regions. Finally, there was evidence of progression by grade level. Grade XI students more often mentioned rectilinear propagation explicitly, though misconceptions persisted, suggesting incremental improvement but not a complete conceptual change.

DISCUSSION

The findings confirm that misconceptions about light and shadow formation are widespread among Indonesian high school students, consistent with earlier studies (Putri et al., 2024; Sujarwanto & Abdurrahman, 2021). The dominance of the umbra–penumbra confusion highlights the challenge of teaching extended sources—an area also emphasized by (Soeharto & Csapó, 2022).

The persistence of the light-as-substance model shows that intuitive, pre-scientific reasoning strongly influences student thinking, aligning with reports in both Indonesian and international contexts (Kaltakci-Gurel et al., 2017; Métioui, 2023). Such conceptions are resistant to change because they are rooted in everyday perceptual experience.

Importantly, the use of four-tier diagnostic tests allowed us to differentiate between lack of knowledge and robust misconceptions, supporting claims by (Bhakti et al., 2023; Kunaedi et al., 2024) that multi-tier instruments provide more valid profiles of student understanding. Combined with interviews, these results illustrate that even students who can reproduce ray diagrams often fail to integrate them with real-world phenomena, echoing (Yusnia et al., 2020).

From an instructional perspective, the results reinforce the importance of conceptual-change strategies. As meta-analyses show, refutation texts and cognitive-conflict designs significantly improve science learning (Mufit et al., 2023; Schroeder & Kucera, 2022). In our context, targeted interventions could include: using discrepant events (e.g., two overlapping shadows from dual lamps) to trigger cognitive conflict, guiding students to draw and test ray diagrams under varying source–object–screen conditions, and embedding inquiry-based activities (Rapi et al., 2022; Sapriati et al., 2024) that explicitly contrast intuitive models with observed results. These align directly with the competencies mandated by Kurikulum Merdeka, particularly scientific reasoning and inquiry.

Instructional Implications

Teachers can apply discrepant events by setting up two-lamp experiments that produce overlapping shadows, thereby creating cognitive conflict. This approach has been shown to be effective in conceptual change-based learning (Mufit et al., 2023). Furthermore, students should be encouraged to engage in inquiry-based modeling by drawing ray diagrams for each scenario and then testing their predictions experimentally, a process supported by previous studies (Rapi et al., 2022; Sapriati et al., 2024). In addition, integration into the Kurikulum Merdeka is essential, as its flexible design allows teachers to devote more time to science projects or thematic inquiry, making optics concepts more contextual and hands-on. Such an instructional sequence reflects the principles of guided inquiry, in which students actively investigate phenomena and develop science process skills, as evidenced by previous research (Rismawati et al., 2017). Moreover, the use of simple physics teaching aids within discovery-oriented learning has been shown to significantly enhance students' higher-order thinking skills, indicating that hands-on and exploratory activities are effective in fostering deeper cognitive engagement (Anawati et al., 2020).

Synthesis

This study demonstrates that misconceptions are not isolated mistakes but structured alternative frameworks combining intuition, perception, and partial scientific reasoning. By uncovering how students actually think, teachers and curriculum designers can move beyond rote correction toward reflective engagement with ideas—supporting the long-term goals of *scientific literacy* as envisioned in PISA and Indonesia's national curriculum. This study extends previous diagnostic surveys by providing qualitative evidence of students' reasoning trajectories about shadows. We found that misconceptions are not merely errors but structured alternative frameworks, often blending scientific and everyday ideas. This highlights the need for teachers to design learning activities that not only deliver correct definitions but also engage students in reflective dialogue and model revision.

CONCLUSION AND SUGGESTIONS

This study explored senior high school students' conceptions of light and shadow formation through a qualitative approach combining four-tier diagnostics and semi-structured interviews. The results revealed five major categories of misconceptions: (1) treating light as a substance, (2) reifying shadows as objects, (3) confusing brightness with shadow size, (4) failing to differentiate umbra and penumbra, and (5) difficulty reasoning about multiple light sources. The most prevalent difficulties were with umbra–penumbra distinctions and the light-as-substance model, indicating persistent obstacles in grasping fundamental principles of rectilinear propagation and source geometry. Interviews confirmed that students often rely on everyday phenomenology ("light sticks," "shadows come out of objects"), blend scientific diagrams with naïve beliefs, and only a minority consistently apply scientific reasoning. This shows that misconceptions are not random errors but structured alternative frameworks that must be deliberately addressed.

The findings suggest several important implications for classroom practice. Teachers should employ discrepant events—such as overlapping shadows from two lamps—to induce cognitive conflict and stimulate conceptual restructuring. In addition, inquiry-based activities that integrate ray diagram predictions with hands-on validation can strengthen students' ability to connect geometrical reasoning with observational evidence. Furthermore, alignment with the Kurikulum Merdeka framework provides greater flexibility to embed inquiry sequences, project-based learning, and formative diagnostic assessments that specifically address optics-related misconceptions.

Future research should consider expanding the scope of participants across diverse regions and school types in order to generalize the findings more effectively. Longitudinal research designs are also recommended to track the durability of conceptual change after targeted instructional interventions. Moreover, exploring the use of digital inquiry tools—such as virtual laboratories and computer-based simulations—may provide new insights into how technology can mediate conceptual change in light and optics.

In conclusion, addressing misconceptions in optics requires not only the transmission of correct scientific knowledge but also pedagogical strategies that confront, question, and reconstruct students' intuitive models. By doing so, physics education can contribute more effectively to the broader goal of improving scientific literacy as mandated in both PISA benchmarks and Indonesia's Kurikulum Merdeka.

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