



## Analysis of Geometric Optics Misconceptions in Physics Pre-Service Teachers Based on a Four-Tier Test Reviewed by Gender and School Origin

Grecellia Mei Magdalena Dakhi\*, Riskan Qadar, Muliati Syam

Faculty of Teacher Training and Education, Mulawarman University, Samarinda, 75123, Indonesia

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#### \* Corresponding author:

E-mail: [grecelliadakhi@gmail.com](mailto:grecelliadakhi@gmail.com)

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### ABSTRACT

Misconceptions in geometric optics are a fundamental problem in physics education, particularly among pre-service teachers responsible for transmitting scientific concepts. Previous studies have mainly focused on general misconceptions and rarely integrated gender and school origin variables into a comprehensive analysis, especially in the context of pre-service physics teachers. This study aims to map the profile of understanding and misconceptions of geometric optics among pre-service teachers, while also examining differences based on gender and school origin. The method used is quantitative descriptive, involving 37 Physics Education students. Data were collected using a Four-Tier Diagnostic Test and analyzed through concept percentages and difference tests (t-test and Mann-Whitney). Results indicate that 66.14% of students were in the concept understanding category, while 19.86% had strong misconceptions, especially on the subconcept of concave mirrors. Descriptively, female students and students from urban areas showed higher understanding than male students and students from rural areas, although no statistically significant differences were found. These results expand the literature on optical misconceptions by revealing conceptual patterns influenced by students' background characteristics. These results highlight the need for adaptive learning strategies, including visual-spatial approaches and interactive simulations.

## 1. Introduction

Geometric optics is one of the fundamental concepts taught at various levels of physics education and plays an important role in helping students understand light phenomena and their relationship to various optical instruments (Eshchanov et al., 2021; Kemp et al., 2020). Optics are applied extensively in everyday life, such as in modern technology, cameras, microscopes, telescopes, and medical instruments

(Grif et al., 2024). In the context of pre-service physics teacher education, mastery of geometric optics is a crucial aspect because a strong conceptual understanding will influence the quality of their future teaching. However, various studies show that optics is one of the topics that most often causes misconceptions due to its abstract nature and the high level of spatial visualization skills it requires, as explained by Galili and Hazan (2000, as cited in Tural, 2015), and supported by findings from Sebald et al. (2022).

Misconceptions are defined as understandings that do not correspond to scientific concepts even though individuals have undergone formal learning processes (Fariyani & Rusilowati, 2017; Rohmah & Priyono, 2023). In geometric optics, misconceptions often arise in the material on reflection, refraction, the nature of images, and the behavior of mirrors and lenses (Admoko et al., 2018; Handayani & Arifin, 2021). For pre-service physics teachers, the existence of these misconceptions is even more critical because they can be carried over into teaching practice and affect their students' understanding in the future (Wahyuni & Taqwa, 2022; Kaltakci-Gurel, 2023).

Previous studies have examined misconceptions about optics among high school students and college students in general (Admoko et al., 2018; Uwamahoro et al., 2021). However, research focusing on pre-service physics teachers is still very limited, even though this group consists of prospective educators who need a deeper understanding of the structure of physics knowledge, whether factual, conceptual, or procedural (Fitri et al., 2024). In addition, many studies on gender differences in physics education emphasize aspects such as achievement, attitude, or self-confidence (Madsen et al., 2013; Musters et al., 2024), rather than on misconceptions of geometric optics. Similarly, research on school origin (urban vs. rural) often focuses on differences in learning facilities and science literacy (Astalini et al., 2023; Suryadi et al., 2020), but has not yet correlated it with misconceptions in optics.

Therefore, there is an important research gap, no study has simultaneously examined the influence of gender and school origin on misconceptions of geometric optics among pre-service physics teachers using a four-tier diagnostic test. In fact, the four-tier instrument has been proven to be more sensitive in detecting reasons for thinking, sources of misconceptions, and respondents' confidence levels compared to traditional multiple-choice tests (Kaltakci-Gurel et al., 2017; Treagust, 1988).

Based on this gap, this study was conducted to map the understanding of concepts and misconceptions of geometric optics among pre-service physics teachers and to analyze the differences based on gender and school origin. Theoretically, this study contributes to enriching the literature on misconceptions in optics by presenting an analysis based on two demographic variables that have rarely been combined before. Practically, the findings of this study can be used as a basis for designing more adaptive, contextual, and inclusive geometric optics learning strategies for pre-service physics teachers.

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## 2. Methodology

### *Participants*

The research participants consisted of 37 students from the Physics Education Study Program at Mulawarman University who were taking the Geometric Optics course. Purposive sampling was used to ensure that all respondents had learned about geometric optics and were willing to participate in the study. The demographic data collected included gender (male/female) and school origin (urban/rural). These variables were used to evaluate the possibility of variations in misconceptions based on the characteristics of the students' backgrounds.

### *Instruments*

The main research instrument was the Four-Tier Diagnostic Test, which consisted of 33 questions on five subconcepts of geometric optics: flat mirrors, concave mirrors, convex mirrors, convex lenses, and concave lenses. The four-tier instrument was chosen because it provides more in-depth information than traditional multiple-choice tests by measuring Conceptual answer, Reason for choosing the answer, Level of confidence, Reason for level of confidence. This instrument refers to the format developed by (Kaltakci-Gurel et al., 2017; Treagust, 1988) and has been widely used to identify misconceptions in optics (Fariyani & Rusilowati, 2017). An example of a four-tier diagnostic test item used in this study is shown in Figure 1, illustrating how each tier functions to detect students' conceptual understanding and reasoning patterns.

1. Soal tier 1  
Waktu itu aku menulis kata "ASA" di papan tulis, lalu aku berdiri dan melihatnya melalui cermin datar. Saat kulihat, bentuk huruf-hurufnya terlihat agak berbeda dari yang kutulis. Kira-kira, bagaimana ya tampilan kata itu di bayangan cermin?
  - a. Sama persis "ASA"
  - b. "ASA" terbalik kiri-kanan
  - c. "ASA" terbalik atas-bawah
  - d. Huruf tidak terlihat
- Tier 2 (Keyakinan 1)  
Seberapa yakin Anda dengan jawaban Anda?
  - a. Sangat yakin
  - b. Yakin
  - c. Tidak yakin
  - d. Sama sekali tidak yakin
- Tier 3 (Alasan):
  - a. Cermin datar memantulkan huruf tanpa perubahan.
  - b. Cermin datar membentuk bayangan simetris kiri-kanan.
  - c. Terbalik atas-bawah hanya terjadi pada cermin lengkung.
  - d. Huruf tidak bisa hilang di cermin datar.
- Tier 4 (Keyakinan 2)  
Seberapa yakin Anda dengan alasan Anda?
  - a. Sangat yakin
  - b. Yakin
  - c. Tidak yakin
  - d. Sama sekali tidak yakin

Figure 1. Example of a Four-Tier Diagnostic Test item used in the study

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The validity and reliability of the instrument were validated by experts in the field of optics and then tested on students outside the research sample. Validity testing was conducted using Pearson correlation with the criteria of  $r_{\text{count}} > r_{\text{table}}$  at a significance level of 0.05 (Sugiyono, 2019). The reliability test using Cronbach's Alpha showed  $\alpha = 0.869$ , indicating that the instrument has high reliability in the reliable and consistent category.

### **Data Collection**

Data was collected through the Four-Tier tests administered directly in class and demographic questionnaires regarding gender and school origin. Each student's answer was classified into one of the categories of understanding using the four-tier guidelines as described by Fariyani and Rusilowati (2017) and Kaltakci-Gurel et al. (2017), namely understanding the concept, lucky error (guessing), low misconception, and strong misconception. All responses were documented using a structured answer sheet designed to organize students' answers according to the four tiers of the instrument. The full format of this answer sheet is presented in Figure 2, showing how each response is arranged into conceptual answer, reason for the answer, confidence level, and reason for the confidence level.

**Lembar Jawaban Optika**

Nama :

NIM :

No. Soal	Tier 1	Tier 2	Tier 3	Tier 4	No. Soal	Tier 1	Tier 2	Tier 3	Tier 4
1					26				
2					27				
3					28				
4					29				
5					30				
6					31				
7					32				
8					33				
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									

Figure 2. Four-Tier Diagnostic Test Answer Sheet Format

To further illustrate how the instrument was used during data collection, Figure 3 provides an example of a completed answer sheet filled out by students, showing how their responses were recorded during the test session. This structured documentation enabled a detailed and systematic analysis of students' conceptual understanding and misconceptions.

**Lembar Jawaban Optika**

Nama : Sekar kentya melati  
NIM : 2305036023

No. Soal	Tier 1	Tier 2	Tier 3	Tier 4
1	B	B	B	C
2	A	A	A	B
3	A	C	A	C
4	D	C	A	C
5	B	B	B	C
6	A	C	A	C
7	B	A	B	B
8	B	B	B	B
9	B	C	A	B
10	B	B	B	C
11	A	C	A	D
12	A	C	A	C
13	B	A	B	B
14	B	B	B	C
15	B	C	B	C
16	B	A	B	A
17	B	B	B	C
18	C	C	C	D
19	C	C	C	C
20	D	C	C	D
21	A	C	A	B
22	D	C	A	D
23	C	B	C	B
24	B	C	B	C
25	B	D	B	D

No. Soal	Tier 1	Tier 2	Tier 3	Tier 4
26	A	B	B	D
27	A	B	A	B
28	A	B	A	B
29	A	C	A	B
30	A	C	A	C
31	C	B	C	B
32	B	C	B	D
33	B	D	A	D

Figure 3. Optics Answer Sheet filled out by research participants

The Figure illustrates how each student's answers are organized into four levels consisting of conceptual answers, reasons for choosing the answers, level of confidence, and reasons for the level of confidence. This structure allows for in-depth analysis of students' understanding and misconceptions.

### Data Analysis

Data analysis was carried out using both descriptive and inferential approaches. Descriptive analysis was used to obtain an overview of the percentage of understanding the concept, lucky error (guessing), low misconception, strong misconception, both overall and per subconcept of geometric optics. The percentage is calculated using the formula:

$$\text{Percentage} = \frac{\text{Total number of categories}}{\text{Total number of students}} \times 100\%$$

(Sugiyono, 2019)

Inferential analysis was used to determine whether there were significant differences in concept understanding and misconceptions based on gender and school origin. The steps were as follows normality test to identify the type of parametric or non-parametric test, The independent samples t-test was used if the data were normally distributed, while the Mann–Whitney U test was used if the data were not normally distributed. The significance level was set at  $p < 0.05$ . The use

of these two statistical tests aligns with recommended comparative analysis procedures in physics education research involving small sample size (Madsen et al., 2013).

### ***Ethical Considerations***

All students were given an explanation of the research objectives and gave their consent to participate. The confidentiality of the collected data was maintained, and it was used solely for academic purposes.

## **3. Results and Discussion**

This study involved 37 pre-service physics teachers, consisting of 31 female and 6 male students, as well as 22 students from rural schools and 15 students from urban schools, who were enrolled in the Physics Education Study Program at Mulawarman University. The students had previously taken physics courses that covered geometric optics in theory, but their hands-on laboratory experience was still limited. The composition of the class and the number of students allowed for the implementation of group activities and individual assessments, so that each student's understanding could be evaluated comprehensively. The diversity of gender and school backgrounds provided an opportunity to explore differences in conceptual understanding and misconceptions among students.

Prior to the study, students had gained various learning experiences, including face-to-face lectures, demonstrations, and several laboratory activities related to geometric optics. However, access to laboratory equipment and simulation media varied, especially for students from schools in rural areas. Some students reported limited experience in conducting direct experiments, which could affect their initial understanding and readiness to participate in activity-based learning or more interactive concept exploration during the study. The initial conditions of this class were an important context in interpreting findings related to misconceptions and conceptual understanding.

During data collection, students continued to follow their usual learning activities, namely lectures, laboratory practicums, and PJBL. These activities provided students with the opportunity to understand optical concepts conceptually, while also preparing data for analysis using the Four-Tier Diagnostic Test. There were eight learning sessions, each lasting 120 minutes. Data were collected through the Four-Tier Diagnostic Test, which assessed conceptual understanding and misconceptions in five subconcepts of geometric optics. This instrument is described in detail in the Methods section (Figure 1), which shows examples of the Four-Tier Diagnostic Test questions used in this study, so that readers can understand the types of questions and the context of data collection. With this context, the analysis of the results presented below can be understood more fully.

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This section presents the main findings of the study, which include: (1) The profile of understanding and misconceptions of optics geometry among physics pre-service teachers, (2) The tendency of misconceptions based on subconcepts, (3) Comparison of understanding and misconceptions based on school origin, and (4) Differences based on gender.

### ***The profile of understanding and misconceptions of optics geometry among physics pre-service teachers***

In general, 66.14% of students were in the category of understanding the concept, 11.18% were in the category of lucky error, 2.84% were in the category of weak misconception, and 19.86% were in the category of strong misconception. These findings indicate that nearly 1 in 5 pre-service teacher students still have quite deep misconceptions about geometric optics. This pattern is consistent with previous studies stating that optics is a physics topic that tends to produce persistent misconceptions (Admoko et al., 2018; Sebald et al., 2022). The Four Tier Diagnostic Test Analysis shows variations in the level of understanding and misunderstanding in five geometric optics subconcepts, highlighting common misunderstandings in each subconcept. The results of the analysis showing the students' concept profiles can be seen in Table 1 below.

Table 1. Understanding and Misconceptions Profile per Subconcept

<b>Subconcept</b>	<b>Understanding the concept %</b>	<b>Lucky error (guessing) %</b>	<b>Low misconception %</b>	<b>Strong misconception %</b>
Flat Mirror	73.4	7.7	0.4	18.5
Concave Mirror	58.4	4.3	3.2	34.1
Convex Mirror	55.7	24.3	5.4	14.6
Convex Lens	71.6	8.1	2.4	17.9
Concave Lens	71.6	11.5	2.7	14.2

The highest percentage of concept understanding was found in convex lenses and concave lenses (71.6% each), while the highest misconception was found in concave mirrors (34.1%). These results are consistent with Kaltakci-Gurel (2023), research that the concept of concave mirrors is one of the most difficult parts of optics for pre-service physics teachers, even when they have high confidence in their incorrect answers.

The misconceptions identified in this study indicate that students have not fully mastered the conceptual knowledge structure in optics. Many students still rely on intuitive reasoning and procedural knowledge without understanding the deeper conceptual foundations. These findings are in line with Fitri et al. (2024), who stated that pre-service physics teachers often master procedural aspects but are weak in conceptual aspects and spatial visualization. This explains why some students can answer correctly but fall into the lucky error category, which describes unstable understanding. Furthermore, strong misconceptions about concave mirrors indicate

that the concepts of real and virtual images, focal position, and curvature points are abstract and require high spatial coordination.

***Misconception specific findings per subconcept:***

***Flat Mirror***

Students often perceive shadows on flat mirrors as real shadows and have difficulty understanding the phenomenon of double reflection, leading them to incorrectly determine the number of shadows. This finding is consistent with the results of Çelikkanlı & Kızılcık (2022), which states that understanding of shadows is often influenced by everyday visual intuition.

***Concave Mirror***

This is a subconcept with the highest number of misconceptions. Common errors include assuming that concave mirrors always produce magnified images, not understanding that objects at the focal point produce images at infinity, confusing the concept with convex mirrors when determining the nature of distant objects' images.

***Convex Mirror***

Most students believe that convex mirrors can produce real or enlarged images, when in fact the images they produce are always virtual, upright, and reduced in size (Fariyani & Rusilowati, 2017).

***Convex Lens***

A common misconception is that students consider convex lenses to be divergent lenses, relying on their physical shape without understanding the concept of light refraction conceptually.

***Concave lens***

There are still students who believe that concave lenses can form real or enlarged images. This finding is in line with Tural (2015), about the difficulty of visualizing shadows on divergent lenses.

***Comparison of understanding and misconceptions based on school origin***

The understanding of concepts among students from urban and rural areas shows descriptive differences, although these are not statistically significant. Table 2 shows the understanding of concepts based on school origin.

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Table 2. Conceptual Understanding Based on School Origin

<b>Subconcept</b>	<b>Urban (%)</b>	<b>Rural (%)</b>
Flat Mirror	80.0	68.8
Concave Mirror	62.7	55.5
Convex Mirror	64.0	51.8
Convex Lens	73.0	71.0
Concave Lens	73.3	70.5
Average	70.6	63.52

Students from urban areas consistently demonstrate a better understanding than students from rural areas. Descriptive differences between urban and rural students indicate that prior educational backgrounds can shape different patterns of initial understanding. Urban students show a higher average understanding (70.6%) than rural students (63.52%). This condition can be explained by the findings Astalini et al. (2023) & Suryadi et al. (2020) which show that schools in urban areas tend to have better access to laboratories, simulation devices, and teachers with higher pedagogical qualifications. In addition, Falentino et al. (2024) also revealed that the differences in achievement and participation in the National Science Olympiad between Java and non-Java regions are closely related to better access to educational facilities in urban areas, which enrich students' practical and simulation experiences. Therefore, students from rural areas often find it difficult to access the same facilities, which contributes to their low understanding of practice-based learning.

The t-test results show a p-value of 0.183 ( $p > 0.05$ ), indicating that there is no significant difference between the two groups. However, this descriptive pattern still has important implications. Students from schools with limited facilities are likely to have less experience with optics practicals, so they tend to rely on memorization or intuitive visualization. This makes them more susceptible to misconceptions derived from everyday visual experiences, such as assuming that a convex mirror can produce a real image or that a concave lens can form a magnified image.

### ***Comparison of understanding and misconceptions based on Gender***

Students' understanding of concepts based on gender shows descriptive differences, although these are not statistically significant. Table 3 shows descriptive differences, although these are not statistically significant.

Table 3. Conceptual Understanding Based on Gender

<b>Subconcept</b>	<b>Male (%)</b>	<b>Female (%)</b>
Flat Mirror	71.4	73.7
Concave Mirror	63.3	57.4
Convex Mirror	36.7	59.4
Convex Lens	56.0	75.0
Concave Lens	62.5	73.4

Descriptively, this study shows that female students have a better understanding of concepts than male students in most subconcepts. Although these differences are not statistically significant, this trend is still interesting to analyze. Madsen et al. (2013), reported that gender differences in physics learning generally appear in problem solving and visual-spatial decision making, where males tend to be more impulsive in answering but less thorough in checking the consistency of reasons and concepts. This is consistent with the findings of this study, which shows that males have a higher percentage of strong misconceptions about concave lenses and concave mirrors.

Results of the Mann–Whitney test showed  $p = 0.550$  ( $p > 0.05$ ), indicating no significant difference based on gender. This finding is consistent with the report by Musters et al. (2024), that gender-based differences in physical performance are often apparent in descriptive accounts but are not always statistically significant. Based on educational psychology, female students tend to show more systematic and detail-oriented learning strategies, so they're more careful in choosing answers and reasons. On the other hand, male students often show high confidence even when their answers are wrong, a phenomenon that's in line with the concept of overconfidence bias that's often reported in science education research (Musters et al., 2024).

This finding has direct implications for teaching geometric optics to pre-service physics teachers. A visual-spatial simulation-based approach, such as PhET simulations or digital ray tracing, is needed to address misconceptions about concave mirrors and diverging lenses. The integration of physical and virtual laboratories can help students from rural school backgrounds who may have limited laboratory experience (Chairunisa, 2024; Novitasari et al., 2021), and the need for differentiated teaching based on student profiles that can be applied by providing: Conceptual exploration activities for female students, Hands-on experiments or model-based reasoning for male students, Additional support for students from rural areas who have limited access to laboratories. There is a need for remediation of misconceptions based on cognitive conflict, especially in subconcepts with strong misconceptions. With this differentiated approach, the optics learning process for pre-service physics teachers can become more inclusive and effective.

#### **4. Conclusion**

This study shows that misconceptions about geometric optics remain a significant conceptual problem for pre-service physics teachers. Approximately one in five students fall into the category of strong misconceptions, with the subconcept of concave mirrors being the area that causes the most conceptual errors. Although most students have understood the basic concepts of lenses and flat mirrors, the existence of lucky errors and weak misconceptions indicates that their understanding is not yet fully stable and still requires conceptual reinforcement.

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Descriptive differences based on gender and school origin show a consistent pattern: female students and students from urban areas have a better understanding than other groups. However, statistical tests show no significant differences, so these two variables cannot be considered the main factors causing misconceptions. Nevertheless, this descriptive pattern remains important because it reflects variations in learning experiences and different styles of information processing among each group.

Theoretically, this study expands our understanding of misconceptions in optics by integrating two background variables gender and school origin which have rarely been studied simultaneously in populations of pre-service physics teachers. These findings confirm that misconceptions are not only cognitive in nature, but are also influenced by self-confidence, learning experiences, and visual-spatial abilities. Practically the results of this study emphasize the importance of implementing more adaptive optics learning strategies, such as the use of visual simulations, ray-tracing approaches, and cognitive conflict-based learning. Laboratory facilities and structured practical activities are essential, especially for students from regions with limited access to education. In addition, lecturers need to design differentiated learning activities that take into account the diversity of students' learning styles so that the process of remedying misconceptions can take place more effectively.

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