



Investigation of High School Students' Conceptual Understanding of Light Waves: Survey in West Java

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Abstract: Conceptual understanding is key to learning. It serves as the groundwork that enables students to apply concepts and build higher-order skills. However, previous studies have shown that students' conceptual understanding of light waves remains limited, and comprehensive data across multiple regions are still lacking. This study investigates students' conceptual understanding of light waves in West Java. The sample comprised 189 twelfth-grade students who had completed instruction on light waves, selected using a random sampling technique. Employing a survey design with a quantitative descriptive approach, data were analyzed using Rasch Model techniques. The instrument used was a 29-item multiple-choice Light Phenomena Conceptual Assessment (LPCA) which has been validated and reported as reliable. Based on person logit scores, results indicate that 58.73% of students fall into the low-ability category, 26.98% into the medium category, and 14.29% into the high category. These results indicate that majority of students have not yet attained an adequate level of conceptual understanding and still experience difficulties in understanding light wave concepts, which may limit their problem-solving abilities. These outcomes can inform educators and researchers in designing instructional strategies and learning media to more effectively teach light wave concepts and thereby improve students' conceptual grasp.

Keywords: Conceptual understanding; Light waves; West Java

Introduction

21st-century education faces the challenge of improving students' achievement alongside the development of various skills. According to Binkley et al. (2012) there are four categories of 21st century skills, namely ways of thinking, ways of working, tools of working, and living in the world. One of the categories is ways of thinking, which include creativity and innovation; critical thinking, problem solving, and decision making; learning to learn and metacognition. These skills represent high-order competencies that require prior conceptual understanding in order to be acquired by students and applied in everyday life.

Conceptual understanding is a cognitive level (C2) according to Bloom's taxonomy. Cognitive processes in understanding include interpreting, exemplifying,

classifying, summarizing, inferring, comparing, and explaining (Anderson & Krathwohl, 2001). Conceptual understanding serves as the foundation for the development of problem-solving, creative thinking, and critical thinking skills (Makhrus et al., 2021).

Conceptual understanding is key to learning. Students have to understand the concept first, so they apply their knowledge in varied contexts (UOTP, 2025). Conceptual understanding not only involves knowing or memorizing materials, but also connecting new concepts and existing concepts in class. Student who do not understand the concepts will make them difficult to apply it and solve physics problem (Putri et al., 2024). Conceptual understanding is connected with problem-solving abilities (Song, 2018). If they can take what they've learned in one situation, adapt and apply it to solve a problem it's a hallmark of proper comprehension

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(UOTP, 2025). Constructivist psychologists and researchers talked about conceptual understanding which is how students attempt or use the knowledge that they have learned to generate explanations of their experience in learning the concept (Pines & West, 1986). So, students have to understand the concept first, then they can apply it to daily life problems.

Light wave is amongst the most abstract domains of physics (Mešić et al., 2016). We interview some teachers in West Java, they said students struggle to understand many rules in light waves concept like special rays in optical system and Snellius’ law of refraction. Students are also struggling to conceptualize how light propagates through different media and slit (single slit, double slit, and diffraction grating). There are many light phenomena in daily life, like mirroring, rainbows, thin-film interference, mirages, polarized sunglasses, etc.

According to Nasir et al. (2021) Ndiwokubwayo et al. (2020) Planinić et al. (2024), Puspaningtyas et al. (2021), student had difficulty understanding concept such as causes of refraction between two medium, visualize geometric optics especially spherical mirrors and lens; and interference concept in analyzing the phenomenon of light waves. Even in the topic of waves, students still demonstrate a low level of conceptual understanding (Devy et al., 2022; Fitriani, 2023). This finding indicates that wave concepts remain among the physics topics that students find difficult to understand, because waves exhibit various counterintuitive properties (Fitriani, 2023).

However, there is still a lack of research investigating students’ conceptual understanding of light waves in West Java. A previous study by Aminudin et al. (2019) investigated students’ conception of light wave concepts among 26 sundanese-students (West Java ethnic) in Ciamis, West Java. Aminudin et al. (2019) reported that almost all students answered misconceptions in their questions. However, the study was limited to a sample of 26 students from a single region and did not include participants from multiple regions in West Java. Such an investigation remains necessary to identify the current level of student’s conceptual understanding of light wave in multiple region of West Java.

This study is necessary especially in the post-COVID-19 pandemic era, due to the impact of learning loss during remote learning, and education systems have transformed from online learning habits to offline learning. This condition may have affected their conceptual understanding, as noted by Susanti et al. (2024), who reported that students in the post-pandemic period exhibit low motivation and reduced achievement in learning physics. Furthermore, the contribution of this study lies in its comprehensive analysis of students’

conceptual understanding of light waves across multiple regions in West Java using the Rasch model analysis. Rasch model analysis.

The Rasch model enables the estimation of students’ abilities on a common scale, thereby allowing for a detailed examination of the distribution of ability levels across individuals (Sumintono & Widhiarso, 2015). Moreover, the Rasch model strengthens the validity of assessment results by identifying irregular response patterns, such as random guessing and potential cheating behavior, which are typically undetected in traditional analyses.

Therefore, this research is important because it provides empirical evidence that can assist educators or teachers in designing appropriate instructional materials for teaching light waves as an abstract domain of physics. The findings of this study are expected to contribute to improving physics education by addressing misconceptions and enhancing students’ conceptual understanding. This study aims to investigate students’ conceptual understanding of light waves in West Java.

Method

Population of the research

The Population of this study consists of 12th-grade students in West Java province majoring in mathematics and natural science (MIPA) who have studied the topic of light waves. Sample of this study was chosen through random sampling. The distribution of student numbers by region is presented in the table 1.



Figure 1. Map of West Java (Google Map, 2026)

Table 1. Number of Student Based on Region

Region	Number of students	Students’ code
Bogor	4	S001-S004
Cikampek, Karawang	5	S035-S039
Bandung	82	S108-S189
Sukabumi	98	S005-S034 S040-S107
Total	189	

Research Methods

This study is a survey research that employed a quantitative descriptive method. In a cross-sectional survey design, the researcher collects data at one point in time, does not track changes over time (Cresswell & Guetterman, 2019). The goal of descriptive method was to provide insight into the characteristics or phenomenon of the population under investigation and does not try to establish a causal relationship (Slater & Hasson, 2024; Sofya et al., 2024). The quantitative descriptive design can use mean, median, and standard deviation analysis to explore the phenomenon (Cresswell & Guetterman, 2019). This study employs a quantitative descriptive design using the Rasch Model analysis to provide insight into students' conceptual understanding in West Java.

This study used 29-item multiple choice light phenomena conceptual assessment (LPCA) developed by Ndiokubwayo et al. (2020), which has been tested for validity and declared reliable. The material assess by the instrument is the topic of reflection, refraction, Snells law, wavelength and frequency, light scattering, interference of light, electromagnetic spectrum, and human eye, focusing on light phenomena in daily life, such as blue sky, orange sky, thin-film soap bubbles, etc. Distribution of test item presented in Table 2.

Table 2. Distribution of Test Item

Concept	Item's Code
Reflection and Refraction (include Snells Law)	I4, I5, I6, I7, I8, I9, I10, I12, I15, I16, I27
Wavelength and frequency	I11, I26, I28
Light scattering	I17, I18, I19, I20, I21
Interference of light	I29
Electromagnetic spectrum	I13, I14, I22, I23, I24, I25
Human eye	I1, I2, I3

Data Analysis

Conceptual understanding ability data analysis with a quantitative method using Rasch Model through Winsteps 4.70 version. According to Sumintono et al. (2015), Rasch model is statistic method to analyze student ability based on each person and the difficulty of item. Assessment analysis using the Rasch model can provide comprehensive information regarding the quality of the instrument used, the quality of the respondents, and the correlation between items and respondents (Sari & Mahmudi, 2024).

To exaime the consistency of items and students responses can be determind by item and person reliability analysis. Item and person reliability were categorized based on Cronbach's alpha value (Sumintono & Widhiarso, 2015; Yuberti et al., 2024). According to Sumintono et al. (2015), category of item and person reliability presented in Table 3.

Table 3. Interpretation of Cronbach's Alpha Value

Cronbach's Alpha	Interpretation
$\alpha > 0.94$	Special
$0.91 \leq \alpha \leq 0.94$	Very Good
$0.80 \leq \alpha < 0.90$	Good
$0.67 \leq \alpha < 0.80$	Fair
$\alpha < 0.67$	Weak

The students' conceptual understanding ability will be grouped based on the logit scores of the person measure table and the wright map. Logit scores represent students' ability, which determines their probability of answering an item correctly. Wright map can provide a powerful visual to document the hierarchy of items and assess an instrument's strengths and weaknesses (Boone & Noltemeyer, 2017).

Rasch model analysis also can assess the alignment of students' ability and detect potential cheating based on person fit-order output. Furthermore, a more advanced analysis was conducted using scalogram analysis, which organizes students' responses according to item difficulty levels. This analysis is useful for examining the consistency of students' responses and identifying deviations or irregularities in response patterns.

According to Sumintono et al. (2015), person fit analysis uses specific criteria to determine alignment of student ability, namely under the condition that The acceptable ranges are as follows: Outfit MNSQ (0.5-1.5), Outfit ZSTD (-2.0 to +2.0), and Point Measure Correlation (0.4-0.85).

Students who do not meet the above criteria are classified as misfitting, indicating response inconsistencies or unexpected response patterns that may be associated with guessing, cheating, lack of concentration, or possible collaboration. Scalogram analysis also needed to gather more information about students' response patterns.

Result and Discussion

Item and Person Reliability

Although the instrument has been tested for validity and declared reliable, we decided to analyze item reliability to ensure the quality of the instrument. We also analyze the person reliability to examine consistency of students' responses. Item and person reliability can be analyzed by examining the visual display generated by the Winsteps application in Output Table 3.1: Summary Statistics.

According to Figure 2, item reliability of 0.95 indicates that the instrument's internal consistency is in the special category, so this instrument quite stable for measuring students' conceptual understanding. Person

reliability of 0.79 indicates that students' response has a fairly good level of reliability

Person	NO INPUT	NO MEASURED	INFIT	OUTFIT
MEAN	13.3	29.8	.99	1.02
P_50	5.5	.0	.95	1.1
REAL RANGE	.AA TRUE SD	.86 SEPARATION	1.84	Item RELIABILITY .79

Item	NO INPUT	NO MEASURED	INFIT	OUTFIT
MEAN	98.3	189.8	1.01	1.02
P_50	27.3	.0	.94	1.7
REAL RANGE	-.17 TRUE SD	.72 SEPARATION	4.18	Item RELIABILITY .95

Figure 2. Item and person reliability

Distribution of Students' Understanding Ability

Students' ability levels can be analyzed by examining the visual display generated by the Winsteps application in Output Table 1: Variable Map. This output known as the Wright Map, illustrates the distribution of students' abilities and item difficulty levels, ranging from high to low categories. The Wright Map helps analyze the distribution of students' conceptual understanding based on logit scale. The Wright Map of students' ability is presented in Figure 3.

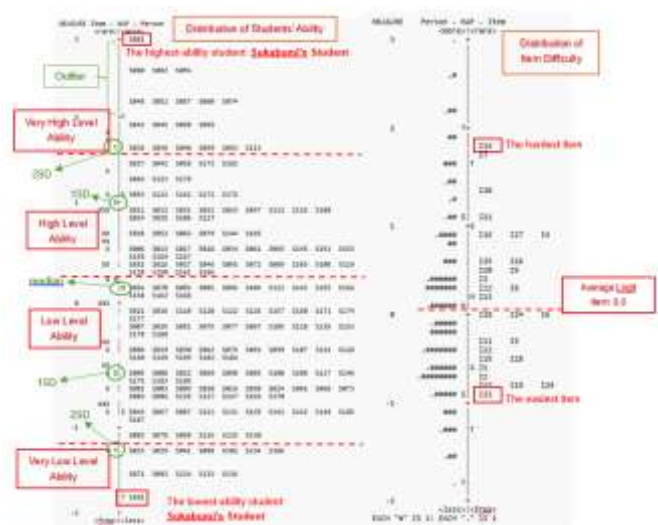


Figure 3. Person-item wright map

According to Figure 3, left-side Wright Map is the distribution of students' ability and the right-side Wright Map is the distribution of item's difficulty of LPCA instrument. Based on the Wright Map, there is one student with code S081 who has the highest-level conceptual understanding ability among all students. There is one student with code S101 who has the lowest-level conceptual understanding ability among all students. S081 and S101 are student from same city, Sukabumi. S081 has a +2.85 logit value, and S101 has a -2.01 logit value (Figure 3). However, nine students (S081, S080, S082, S094, S048, S052, S057, S060, S074) are identified as outliers, including the highest-level ability, S081. Their positions deviate substantially from the

general pattern on the logit scale. This indicates that their abilities are not aligned with the difficulty level of test item, such as high-ability students being unable to answer difficult items. This phenomenon will be further analyzed through a scalogram analysis. In addition, students identified as outliers may exhibit inconsistent response patterns (misfit). Therefore, the misfit order will be further examined and discussed in the person fit order analysis.

Based on the Wright Map, the item with code I14 is the hardest item and I23 is the easiest item. I14 has a +1.65 logit value and I23 has a -1.09 logit value (Figure 3). I14 is a test item about relationship between atomic excitation and the electromagnetic spectrum. Item I23 is a test item about the role of the ozone layer in filtering harmful electromagnetic radiation. Measure column in Figure 2 presented the logit value of item. The logit value corresponds to the total score column. Total score column in Figure 4 presented numbers of students who answer the item correctly. Therefore, a higher logit value indicates a higher of item difficulty.

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	S.E.	INFIT	OUTFIT	PTMEASURE-AL	EXACT MATCH	Item
14	35	109	1.65	.20	1.41	3.02	1.73	3.21	I14
7	58	109	1.53	.20	1.38	2.40	1.54	2.75	I17
10	47	109	1.20	.18	1.41	3.74	1.47	2.91	I10
21	57	109	.88	.17	1.38	1.19	1.18	1.92	I21
27	84	109	.67	.17	.96	-.27	1.01	1.22	I27
4	65	109	.65	.17	.88	1.62	.83	1.79	I4
18	68	109	.65	.17	1.25	1.87	1.17	1.03	I18
26	73	109	.62	.16	.92	1.81	.91	1.99	I26
25	75	109	.37	.16	.94	-.93	.88	-1.48	I25
20	77	109	.32	.16	1.05	-.82	1.04	.53	I20
9	79	109	.27	.16	.86	2.34	.86	-1.79	I9
3	82	109	.19	.16	1.17	2.66	1.19	2.17	I3
8	84	109	.14	.16	.92	1.32	.87	-1.59	I8
12	84	109	.14	.16	.96	-.40	.96	-.17	I12
13	91	109	-.04	.16	.92	1.41	.91	-1.07	I13
18	96	109	-.17	.16	.93	1.31	.89	-1.43	I18
6	98	109	-.22	.16	.92	1.41	.90	-1.26	I6
24	88	109	-.22	.16	.92	1.48	.80	-1.74	I24
11	107	109	-.45	.16	.92	1.96	.87	-1.94	I11
5	110	109	-.52	.16	.89	2.18	.85	-1.66	I5
22	112	109	-.58	.16	.96	-.31	.90	-.80	I22
28	116	109	-.68	.16	.91	-1.06	.89	-1.71	I28
15	117	109	-.71	.16	.82	1.39	.75	-2.08	I15
1	118	109	-.73	.16	1.02	1.32	1.00	.80	I1
2	122	109	-.84	.16	1.11	1.75	1.20	2.44	I2
19	125	109	-.92	.17	.89	-1.78	.78	-2.03	I19
29	125	109	-.92	.17	.99	-.21	1.03	.29	I29
17	127	109	-.97	.17	1.09	1.38	1.21	1.63	I17
23	131	109	-1.09	.17	.85	-2.37	.79	-1.69	I23
MEAN	98.3	109.0	.80	.17	1.01	-.31	.82	-.21	
P_50	27.3	.0	.74	.01	.15	1.81	.24	1.71	

Figure 4. Item measure

Data processing related to the classification of students' ability levels and item difficulty levels was analyzed using the output tables generated by Winsteps in Output Table 17: Person Measure. Person Measure Table provides detailed logit information for each individual, presented in Figure 5.

According to Figure 5, mean value of logit is -0.10. The mean of logit value of the items is always set at 0.0 (Figure 2), serving as the reference point of the scale. The man person logit value is below 0.0, indicating that the average student performance is below the average standard item difficulty (Sumintono & Widhiarso, 2015).

INPUT: 100 Person, 20 Item, RELIABILITY: 100 Person, 20 Item, 2 CATS, MEASURES 4,7,0,0
 Person: REAL SEP.: 1.84, REL.: .79, Item: REAL SEP.: 4.18, REL.: .95

Person STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INLET PROG	OUTPUT DIST	DIFFERENCE	EXACT MATCH	Person
01	27	20	2.83	.00	1.81	-1.29	.48	289	99.1
02	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
03	26	20	2.36	.00	1.82	-1.39	.46	241	89.7
04	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
05	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
06	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
07	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
08	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
09	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
10	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
11	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
12	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
13	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
14	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
15	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
16	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
17	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
18	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
19	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
20	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
21	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
22	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
23	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
24	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
25	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
26	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
27	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
28	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
29	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
30	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
31	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
32	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
33	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
34	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
35	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
36	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
37	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
38	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
39	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
40	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
41	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
42	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
43	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
44	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
45	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
46	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
47	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
48	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
49	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
50	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
51	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
52	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
53	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
54	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
55	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
56	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
57	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
58	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
59	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
60	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
61	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
62	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
63	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
64	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
65	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
66	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
67	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
68	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
69	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
70	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
71	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
72	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
73	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
74	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
75	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
76	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
77	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
78	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
79	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
80	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
81	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
82	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
83	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
84	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
85	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
86	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
87	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
88	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
89	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
90	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
91	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
92	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
93	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
94	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
95	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
96	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
97	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
98	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
99	26	20	2.36	.00	1.89	-1.38	.47	241	89.7
100	26	20	2.36	.00	1.89	-1.38	.47	241	89.7

MEAN 13.0 20.0 .30
 P.10 5.5 .8 .87

Figure 5. Person measure

Standard deviation (SD) of the logit value is 0.97. Standard deviation value can be reference point to

classified students' ability (Sumintono & Widhiarso, 2015), as presented in Figure 1. According to Muki et al.

(2025), student ability level can be classified into three general levels: high ability if measure (logit value) > SD, medium ability if mean < measure < SD, and low ability if measure < mean. Based on these criteria, the level of conceptual understanding ability of students in West Java on light waves material can be seen in Table 4.

Table 4. Level of Students' Conceptual Understanding Ability in West Java

Student Ability Level	Number of Students	Percentage (%)
High	27	14.29%
Medium	51	26.98%
Low	111	58.73%

According to Table 4, the majority of students (58.73%) in West Java demonstrate a low level of conceptual understanding of light waves concept. Only 14.29% of students demonstrate a high level of conceptual understanding of light waves concept.

Table 5 presents the level of students' conceptual understanding ability based on region. Students classified at the high ability level were predominantly from Sukabumi, while none of the students from Bogor reached this level. Although the sample was dominated by students from Sukabumi (98 students) and Bandung (82 students), a high proportion of students from Sukabumi (20.4%) attained the high level compared to those from Bandung (6.1%).

Table 5. Level of Students' Conceptual Understanding Based on Region

Region	Number of students		
	High	Medium	Low
Bogor	-	-	4
Cikampek, Karawang	2	-	3
Bandung	5	29	48
Sukabumi	20	22	56

Person-Fit

Person fit analysis to assess the alignment of student ability with the ideal model and to detect potential cheating (Sumintono & Widhiarso, 2015). Person fit can be analyzed by examining the visual display generated by the Winsteps application in Output Table 6: Person Fit Order. Person Fit Order table presented in Figure 6.

Students identified as exhibiting misfit response patterns were classified based on the criteria established by Sumintono et al. (2015). Twelve students were identified as exhibiting misfitting response patterns, namely those with the codes S002, S097, S131, S086, S098, S016, S124, S009, S186, S125, S004, S129. The mean-square values of the twelve students were found to be outside the acceptable range. However, among these twelve students, five met the outfit Z-standard (ZSTD)

criterion, specifically students coded S098, S124, S186, S125, and S129. The point-measure correlation (Pt-Mean Corr) values for all twelve students were outside the permissible limits. Moreover, students S002, S097, S131, S086, S098, S016, S009, S125, S004, and S129 exhibited negative Pt-Mean Corr values, indicating irregular response behavior. The twelve students identified as a misfit response pattern. It is necessary to consider why misfit might be occurring. We can see students' answer pattern (Boone & Straver, 2020). Misfit response pattern indicate these students have inconsistent responses and possible cheating (Sumintono & Widhiarso, 2015). The twelve students identified as misfitting demonstrated lower levels of conceptual understanding of light wave.

According to the Wright Map in Figure 3, there are 9 students (S081, S080, S082, S094, S048, S052, S057, S060, S074) are identified as outliers. We analyse the person fit order of these nine students. The nine students were classified as fitting the model (fit order), indicating that their response patterns were consistent with the ideal model and did not indicate irregular behavior or cheating.

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT	OUTFIT	P-PRESIDUAL	EXACT MATCH	Person				
2	7	20	-1.20	.45	1.26	1.13	1.79	2.93	-17	27	75.9	75.8	S092
97	12	20	-.40	.40	1.52	3.54	1.76	3.66	-39	32	41.4	65.3	S097
131	8	20	-1.09	.43	1.29	1.44	1.68	2.06	-28	28	69.0	72.4	S131
86	9	20	-.90	.42	1.34	1.33	1.67	2.30	-11	30	69.0	69.4	S086
98	7	20	-1.20	.45	1.17	.87	1.67	1.80	-8	27	75.9	75.8	S098
16	8	20	-.90	.42	1.39	2.11	1.66	2.20	-25	30	62.1	69.4	S016
124	5	20	-1.74	.51	1.09	.39	1.65	1.35	6	23	82.8	82.7	S124
9	9	20	-.90	.42	1.29	1.63	1.62	2.19	-14	30	62.1	69.4	S009
186	8	20	-1.50	.47	1.03	.19	1.58	1.40	1	25	79.3	79.3	S186
125	7	20	-1.20	.45	1.17	.87	1.58	1.35	-9	27	75.9	75.8	S125
4	11	20	-.57	.40	1.39	2.54	1.59	2.40	-21	32	44.8	66.1	S004
129	9	20	-.90	.42	1.22	1.28	1.52	1.83	-8	30	69.0	69.4	S129
73	9	20	-.90	.42	1.11	.81	1.40	1.74	-9	30	62.1	69.4	S073
136	8	20	-1.74	.51	1.18	1.69	1.47	1.60	-8	23	82.8	82.7	S136
27	22	20	1.28	.46	1.08	.41	1.40	1.36	12	31	75.9	76.9	S027
113	23	20	1.50	.48	1.09	.41	1.44	1.17	19	30	79.3	79.6	S113
140	8	20	-1.09	.43	1.26	1.52	1.44	1.43	-9	28	69.0	72.4	S140
146	10	20	-.73	.41	1.21	1.52	1.42	1.75	-9	31	65.5	67.4	S146
63	11	20	-.57	.40	1.23	1.69	1.41	1.95	-8	32	58.6	66.1	S063
119	15	20	-.06	.40	1.38	2.03	1.41	2.54	-13	34	44.8	64.6	S119
185	8	20	-1.09	.43	1.10	.57	1.40	1.34	0	28	69.0	72.4	S185
105	12	20	-.40	.40	1.19	1.49	1.39	2.09	-8	32	62.1	65.3	S105
170	12	20	-.40	.40	1.22	1.65	1.39	2.06	-8	32	62.1	65.3	S170
164	11	20	-.57	.40	1.15	1.11	1.38	1.79	-8	32	65.5	66.1	S164
120	13	20	-.25	.40	1.20	2.11	1.37	2.17	-9	33	51.7	64.7	S120
22	10	20	-.73	.41	1.19	1.29	1.36	1.56	-8	31	58.6	67.4	S022
99	11	20	-.57	.40	1.21	1.63	1.35	1.87	-8	32	62.1	62.1	S099
107	8	20	-1.09	.43	1.20	1.69	1.35	1.30	-8	28	69.0	72.4	S107
44	8	20	-1.09	.43	1.15	.84	1.35	1.12	-8	28	69.0	72.4	S044
109	10	20	-.73	.41	1.16	1.04	1.33	1.42	-8	31	65.5	67.4	S109
117	10	20	-.73	.41	1.16	1.03	1.32	1.39	-8	31	58.6	67.4	S117
153	12	20	-.40	.40	1.20	1.52	1.31	1.67	-8	32	58.2	65.3	S153
20	9	20	-.90	.42	1.09	.54	1.30	1.18	-14	30	69.0	69.4	S020
37	15	20	-.06	.40	1.24	1.83	1.30	1.93	-8	34	51.7	64.6	S037
109	10	20	-.73	.41	1.23	1.47	1.30	1.33	-8	31	51.7	64.6	S109
115	7	20	-1.20	.45	1.02	.18	1.29	.91	-19	27	75.9	75.8	S115
3	9	20	-.90	.42	1.04	.30	1.24	1.04	-18	30	60.0	69.4	S003
15	15	20	-.06	.40	1.19	1.44	1.25	1.62	-8	34	58.6	64.6	S015
64	21	20	1.00	.44	1.11	.54	1.25	.95	-14	32	75.9	74.4	S064
100	10	20	-.73	.41	1.04	.74	1.24	1.09	-20	31	79.3	67.4	S100
93	23	20	1.50	.48	1.06	.09	1.23	.71	-28	30	86.2	79.6	S093
143	14	20	-.09	.39	1.13	1.24	1.27	1.51	-12	34	58.6	64.6	S143
18	9	20	-.90	.42	1.14	.18	1.21	.87	-18	30	69.0	69.4	S018
26	15	20	-.06	.40	1.20	1.57	1.22	1.38	-8	34	44.8	64.6	S026
38	23	20	1.50	.48	.99	.04	1.22	.65	-26	30	79.3	79.6	S038
39	23	20	1.50	.48	.99	.04	1.21	.65	-26	30	79.3	79.6	S039
57	23	20	2.03	.54	.89	-.47	1.00	-.17	-46	26	86.2	86.2	S057

Figure 6. Person fit order

Scalogram

Scalogram analysis to examine student responses according to item difficulty levels. Scalogram can be analyzed by examining the visual display generated by the Winsteps application in Output Table 22: Scalogram.

The Scalogram is presented in Figure 7. The scalogram displays students' response patterns by arranging items based on item difficulty, from the easiest (I23) to the most difficult (I14). Also in the scalogram, students are subsequently arranged according to their ability levels, from highest to lowest.

One of the main advantages of the scalogram is its ability to identify potential cheating behaviors, such as students copying from one another or engaging in collusive responding. This is indicated by identical student response patterns, which are highlighted by red lines. A total of 17 students were indicated as potentially engaging in cheating behavior.

Students exhibiting careless response patterns, answering difficult items correctly while failing easy ones, are indicated by orange, blue, and green lines. Items I14 and I7 are classified as difficult, with I14 being the most difficult, and items I1, I2, I17, I19, I29, I23 are classified as easy (based on Wright Map). Orange lines indicate students who answered I14 correctly but missed one or more easy items; blue lines indicate those who answered I7 correctly but missed one or more easy items; and green lines indicate students who answered both I14 and I7 correctly but missed one or more easy items. This lack of carefulness may suggest that some difficult items were answered through guessing.

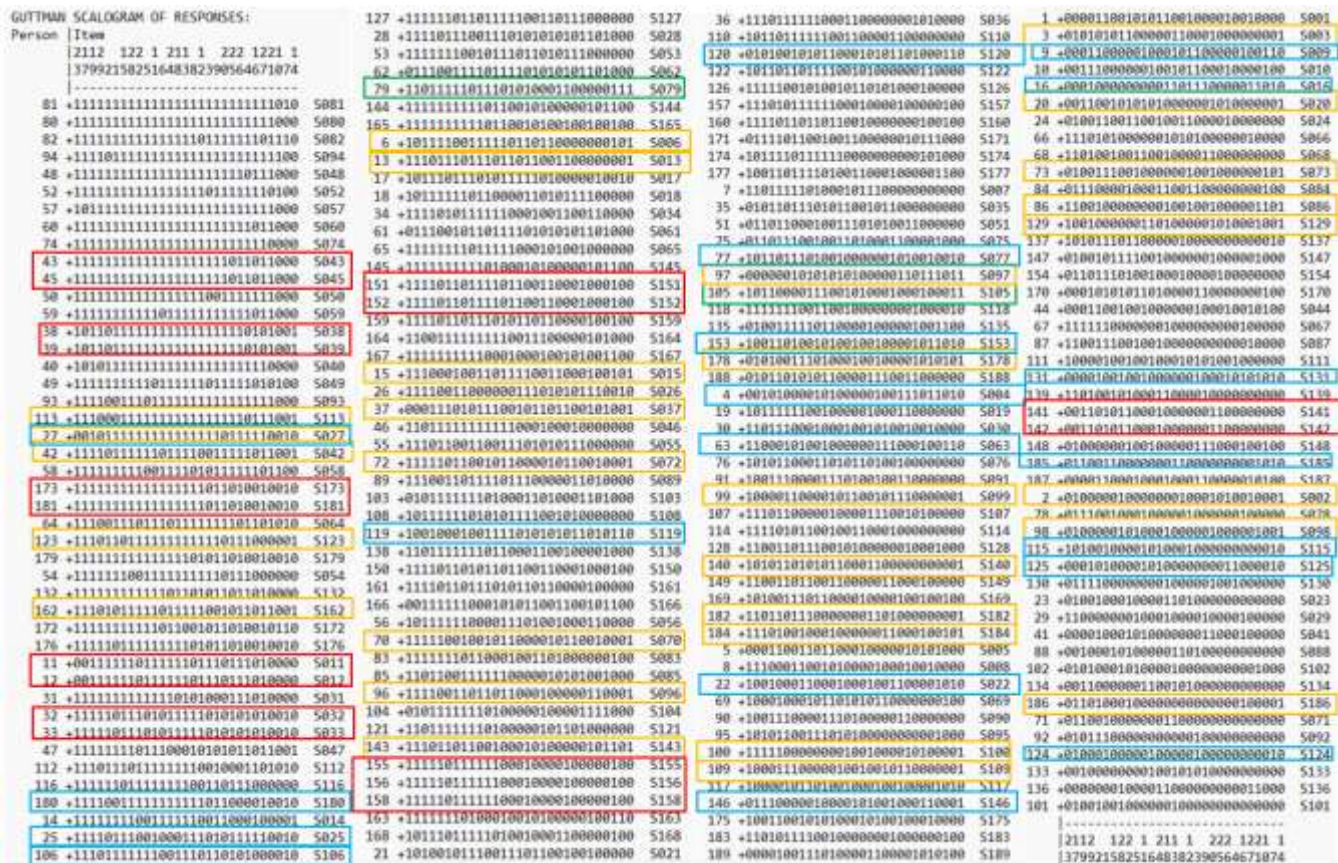


Figure 7. Scalogram

Light waves concepts play an important role in technology and are frequently encountered in everyday life. Such as rainbow, mirroring, thin-film interference, compact disk, glasses, lup, blue sky, red sky, etc. However, many students have struggle in understanding light waves concepts because of its abstractness and difficulty in visualizing. Understanding concepts first is important for students, to apply and elaborate the concepts to solve scientific problems they experience in their daily activities (Arsyad et al., 2020; Estianinur et al., 2020; Nasir et al., 2022).

The research shows that most students have a low ability of conceptual understanding of light wave concepts. Most of students experienced difficulty in answering item I14 and I17. Item I14 is about relationship of energy of excitation atom and electromagnetic spectrum. Item I17 is about light scattering as a cause of orange light. This issue may arise because physics instruction tends to focus on geometric optics in the classroom (Puspaningtyas et al., 2021) while topics such as light scattering and energy of light in electromagnetic spectrum are rarely discussed.

On the other hand, most students demonstrated ease in answering item I23, which evaluates their understanding of the role of the ozone layer in the atmosphere in shielding the Earth from electromagnetic radiation. This may happen because the ozone layer topic is addressed in science learning context, including representation in children's educational materials, secondary schools, and universities (Gungodu et al., 2017; Kazantzidou & Kostsis, 2023) thus, this topic is familiar to students and relevant to their everyday experiences.

According to Table 4, students classified at the high ability level were predominantly from Sukabumi. On the other hand, no students from Bogor were classified at the high ability level. The underlying cause of this phenomenon cannot be conclusively identified, however it may be related to variations in students' learning styles, cultural contexts, and teachers' approaches in teaching (Banner, 2016; Kanli & Ilcan, 2020; Linsiyah et al., 2023; Suciani et al., 2022).

Based on person-fit order in Figure 5, there are twelve students categorized as missfitting, indicating possible cheating because they can answer difficult items but can't answer easy items. This result can be examined in more detail through the scalogram output in Figure 6, which more clearly reveals students who tend to experience ability misfit. This issue may occur because of careless, lucky guesses, and cheating (Sari & Mahmudi, 2024; Sumintono & Widhiarso, 2015). According to the scalogram output, there are seventeen students identified as cheating or collusive responders because they have same answer patterns. This may occur because in some schools, the test was administered via Google Form. Although the test is strictly supervised by teacher, this method still has a possibility of collusion.

The findings reveal that students have difficulty understanding light wave concepts. Therefore, there is a need for concept reinforcement and the development of learning materials that can more effectively visualize abstract concepts such as light waves. Such as interactive media (Asrizal et al., 2025), virtual laboratory (Hamamous & Benjelloun, 2023; Odja et al., 2023; Rahmatullah et al., 2023), android-based interactive mobile learning (Meisaroh & Suparno, 2024), 3D experimental media (Hasnaini et al., 2024; Izzah & Wulandari, 2025), etc. Appropriate learning strategies are also required to strengthen students' understanding of physics concept especially light wave concept, such as inquiry-based learning (Feranie et al., 2023; Haidar et al., 2020; Meisaroh & Suparno, 2024; Quraisy et al., 2025), problem-based learning (Lestari & Setyasto, 2025; Odja et al., 2023), collaborative learning (Hermarini et al., 2019), etc. Learning strategies also provide detailed discussion of confusing phenomena and how scientific conceptions can apply (Makhrus et al., 2023). These

strategies can emphasize students' active roles in investigating and constructing concepts.

Learning would be further enhanced if it is supported by self-regulated learning (SRL) strategies, as this approach supports students in managing their own learning according to their individual learning styles. Self-regulated learning equips students with the ability to become independent learners and to develop high self-efficacy (Schunk & Pajares, 2002; Zimmerman, 2002). This is consistent with studies in science education, particularly in physics, which have shown that self-regulated learning can improve students' academic achievement and self-efficacy (Damayanti et al., 2025; Dewi et al., 2020; Juniari et al., 2021; Valda et al., 2025; Winiari et al., 2019; Zuffiano et al., 2013). Self-regulated learning can help students improve their academic achievement and self-efficacy—both of which are essential for success at higher levels of education.

The implementation of these approaches is expected to strengthen students' conceptual understanding of physics, particularly among students in West Java. Then, they are able to build a strong conceptual foundation and progress from lower-order thinking (remembering and understanding) to higher-order thinking skills, such as analyzing, evaluating, creating, and also emphasize way of thinking such as creativity and innovation; critical thinking, problem solving, and decision making; learning to learn and metacognition.

Conclusion

This research investigated students' conceptual understanding of light wave concepts in West Java. The findings indicate that 58.73% of students are categorized in the low-ability group, 26.98% in the medium category, and only 14.29% in the high category, demonstrating that the majority of students have not yet achieved an adequate level of conceptual understanding. These results confirm the study objective by providing a comprehensive profile of students' conceptual understanding across multiple regions. Additionally, the analysis identified potential instances of cheating or collusive responses, indicated by similar response patterns. Therefore, students identified as having potential cheating or collusive response patterns cannot be reliably evaluated in terms of their true abilities. As a follow-up measure, these students may be required to retake the test under strict supervision to obtain more accurate results. Overall, this study contributes by providing recent and regionally representative data. The results offer important implications for educators and researchers in developing more visual and interactive instructional materials and implementing effective learning strategies to facilitate understanding of abstract

physics concepts, such as light waves. Future research is recommended to involve a broader population across more regions in West Java and to explore instructional interventions to address students' conceptual difficulties.

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Author Contributions

Conceptualization, S.A.N.H. and I.M.S.; methodology, S.A.N.H. and I.M.S.; software, S.A.N.H.; validation, I.M.S.; formal analysis, S.A.N.H. and I.M.S.; investigation, S.A.N.H.; resources, S.A.N.H.; data curation, S.A.N.H., I.M.S., D.R. ; writing—original draft preparation, S.A.N.H. and I.M.S.; writing—review and editing, I.M.S., D.R.; visualization, S.A.N.H.; supervision, I.M.S., D.R. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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