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The Development of a Two-Tier Diagnostic Test for Student Understanding of Light

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ABSTRACT
This study aimed to devlop a two-tier light concept test to identify student concept understanding of light. The development of the test was carried out through the content validity, construct validity, and reliability test stages using the Item Response Theory (IRT). The sample consisted of 81 students during the second semester at five universities in Indonesia. The results showed that the instrument met the content validity and construct validity criteria as well as reliability. Efforts are needed to improve concepts in light material.

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Introduction

Conceptual knowledge is the basis for organizing knowledge and experience into various categories (Arends, 2008). Conceptual knowledge is the basis for higher mental processes. The dimensions of understanding consist of interpreting, exemplifying, classifying, summarizing, inferring, comparing and explaining (Anderson & Bloom, 2001). According to Hamalik (2008), students who understand a concept can name examples of it, state the characteristics of the concept, choose and differentiate categories within the concept, and solve problems that related to the concept. Physics learning problems that are mostly raised by researchers are related to how students understand concepts and apply them to solve problem. Misconceptions brought by students will affect the thinking skills of students in problem-solving. Several research results show that conceptual change requires learning that allows students to develop new concepts and improve previous misconceptions (Jusniar et al., 2021; Phon et al., 2019; Englund et al., 2017; Barlia, 2016; Sellmann et al., 2015). The activities used for conceptual change positively influenced students' problem-solving (Kucukozer, & Kocakulah, 2008). Misconceptions can only be removed by targeting them during teaching (Topalsan & Bayram, 2019).

A challenge for educators is to bring about conceptual change in their learners whenever misconceptions are prevalent. Students bring misconceptions into class that they have built up from interacting with their environment (Suparno, 2013). Identifying student misconceptions is an important step in oriented learning (Eshach, 2014). Misconceptions can be viewed as cognitive structures that are firmly attached to the minds of students and deviate from the conceptions put forward by experts thereby misleading students in understanding natural phenomena and presenting scientific explanations (Hammer, 1996). Misconception causes students to have difficulty solving problems (Hammer, 2000).

The analysis of misconceptions in the field of physics is exemplified by the Four-Tier Diagnostic Test with Certainty of Response Index to Identify Misconceptions in Newton's Law, Fluid, and Work (Maharani et al., 2019; Diani et al., 2019; Yuberti et al., 2020). Misconception analysis using the three-tier concept of chemical bonding, acid, and simple electric circuits (Peşman & Eryılmaz, 2010; Senol & Yilmaz, 2017; Mubarokah et al., 2018). Identification of students' misconceptions using the Certainty of Response Index (CRI) are covalent bonding, mechanics, electricity, work and energy, and higher-order thinking skills (Taber, 2011; Haris, 2016; Azzarkasyi et al., 2019; Mustari et al., 2020; Suprapto, 2020; Mohammad et al., 2020).

Fiber optic was chosen as the context in this study because of the concept of light as the basis for transmitting signals without attenuation. However, there is no research that specifically identifies the concept of light to support fiber optic learning, such as the influence of differences in the refractive index of mediums, critical angles, total internal reflection, attenuation due to absorption, scattering and dispersion. A test targeting these areas would identify the readiness of students to study fiber optic. If weaknesses in prerequisite concepts are not addressed first, students will have difficulties regarding the basic principles of light propagation in fiber optic, and techniques to minimize the attenuation of fiber optic signals.

The relevant research results on understanding the concept of light show that there are many students' misconceptions about light in the 'moderate' category (Munawaroh & Falahi, 2016). A study by Prodjosantoso & Irwanto (2019) applied a categorization of misconceptions as high, moderate, or low. The results of the literature review Onder et al (2022) show that learners' misconceptions use a four-tier diagnostic test without test development process in physics education between 2010 and 2022. In this study began with the development of a light concept diagnostic instrument using item response theory (IRT).

IRT was chosen as the item analysis technique in this study because it aims to overcome the weaknesses found in classical measurements. Classical test theory does not pay attention to how the respondents respond to items. In practice, the respondent's ability is seen based on the total score of the number of correct answers from the respondent, without distinguishing whether the item answered correctly by the respondent is an easy or difficult item. The fundamental difference between classical measurements and modern measurements lies in the invariance of scoring. According to Lord (2008), the invariance of the test item parameters across the test-taker group is the most important characteristic of IRT. Through IRT, the index of item parameters can be known easily (Nurcahyo, 2017). In addition, IRT frees respondents and items from interdependence. IRT estimates of item difficulty do not change from one sample to another; difficulty indicators are also more stable from one form of test to another; IRT internal consistencies are stable from one sample to another; and IRT has significantly less measurement error when compared with Classical Test Theory (Idaka & Idaka, 2014).

Items that have met the IRT criteria are used to measure students' misconceptions with the Certainty Response Index (CRI) analysis technique. The CRI method is a scale of confidence or certainty of respondents in providing answers to each given question (Tayubi, 2005). The CRI technique can not only identify student misconceptions but also can distinguish students who know concepts, students who guessed the answer, and students who do not understand the concept. This study aimed to develop a two-tier diagnostic instrument targeting light concepts relevant to optical

fiber and analyze light concept understanding. Research questions can be formulated as what is the result of the two-tier instrument development?

Methods

Research Design

The test development procedure follows that proposed by Widoyoko (2012) which states that there are nine steps taken in the development of learning outcomes tests, namely: (1) Developing test specifications, (2) Writing test questions, (3) Examining test questions, (4) Conducting test trials, (5) Analysing test items, (6) Improving tests, (7) Assembling tests (8) Conducting wide-scale test, and (9) Interpreting test results. The type of survey used a cross-sectional survey design (Creswell, 2002).

Conceptual knowledge indicators measured in this study include interpreting, exemplifying, classifying, inferring, comparing and explaining. The concept domains, indicators and item numbers are shown in Table 1.

Table 1

Indicators of Understanding the Concept of Light

Concept	Indicator	Item
Light waves	Explains the definition of light as a wave	1
	Identify the type of light wave	2
	Identify the characteristics of the rays	3
	Interpret the direction of the rays against the wavefront	4
Reflection and refraction of light	Explain the Snell's law	5
	Draws inference from the diffuse reflection event	6
	Distinguishes the magnitude of the waves that are constant and change as light waves are refracted	7
	Distinguishing the direction of refraction in mediums that have different refractive index values	8
Critical angle	Explain the definition of a critical angle	9
	Identify the conditions for a critical angle	10
	Interpreting the meaning of the critical angle	11
	Draws inference about the smallest critical angle value from the refractive index data presented	12
Total internal reflection	Explains the definition of total internal reflection	13
	Identifies the conditions for total internal reflection	14
	Interpret the meaning of total internal reflection	15
Wave attenuation	Explain the definition of wave intensity attenuation	16
	Interpreting the meaning of the wave mathematical equation in a conductive medium	17
	Provides an example of a light scattering event	18
	Give an example of a light absorption event	19
	Make inferences about light dispersion event	20

Research Subject

The sample of the survey of the trend understanding of the concept of light consisted of 81 students who were taken from the second semester of five universities in Indonesia. The sample was selected by purposive sampling, namely the technique of determining the sample with certain considerations.

Data Collection Tools

The data collection techniques used in this study were multiple-choice tests, questionnaires, and interviews. Multiple-choice tests measure students correct or incorrect answers. Questionnaires to determine the level of confidence in the answers given and to collect data on the perceptions of experts and practitioners on the items being developed. Interviews were used to collect data on the causes of students' misconceptions and difficulties in answering questions.

Data Analysis

The data analysis technique used in this study follows the model of Miles, Huberman and Saldana (2014): data reduction, data display, and drawing conclusions or verification. Content validity is carried out through expert and practitioner judgments with the main objective of obtaining input from the validator. Experts and practitioners provide criteria, that are highly relevant, relevant, irrelevant, and highly irrelevant. Aiken's validity categories: 0.0 to 0.4 low or cannot be used, 0.4 to 0.8 moderate category or can be used with improvement, and 0.8 to 1.00 including the high category or can be used for research. The construct validity of the instrument was tested using Item Response Theory (IRT). Validity in IRT refers to what extent examinees have a good ranking in the ability which the test items measure the ability of the test to individuals rank according to their ability as well as rank the items according to their level of difficulty (Hambleton, 1994). Reliability according to IRT is an item and test information or, the degree to which an investigator or researcher can be certain of a person's location along ability estimation (θ). The amount of item information is proportionate to the standard error of estimate (SEE) for each possible θ (De Ayala, 2009). A smaller SEE indicates a stronger certainty in the estimate of θ and therefore more information about individuals with that particular θ value. With IRT, items are calibrated without reference to the sample in terms of the trait level or ability level of an individual referred to as θ, and item parameter estimates. The item parameter estimates are item discrimination power (parameter *a*), item difficulty (parameter *b*), and guessing (parameter *c*).

IRT analysis can show the level of difficulty of the items and the level of the test taker's ability to answer questions that the classical test analysis cannot show. The data on the degree of difficulty item question can be seen by using b value in Table 2. (Bichi & Talib, 2018).

Table 2

Degree of Difficulty Item Question

Threshold Value	Note	Item
$b > 2$	Very difficult	0
$1 < b \leq 2$	Difficult	6,12,14
$-1 \leq b \leq 1$	Moderate	18
$-1 > b \leq -2$	Easy	3, 10, 20,7,4,2,8
$b < -2$	Very easy	1,5

The criteria for item quality according to the IRT approach are shown in Table 3 (Setyawarno, 2017).

Table 3

Quality Criteria for Question Items according to IRT

Criteria	Compatibility with the Rasch model		Difficulty index (b)
	infit MNSQ	*outfit t*	
Good	$0{,}77 \leq infit\ mean\ square \leq 1{,}33$	$t \leq 2{,}00$	$-2 \leq b \leq 2$
Quite good	$0{,}77 \leq infit\ mean - square \leq 1{,}33$	$t \leq 2{,}00$	$b > 2$ or $b < -2$
Not good	$infit\ meansquare < 0{,}77$ or $infit\ meansquare > 1{,}33$	$t > 2{,}00$	$b > 2$ or $b < -2$

CRI is based on a scale as shown in Table 4 (Hasan et al., 1999).

Table 4

CRI Assessment Criteria

CRI	Criteria	Confidence Level
0	Guessed answer	Low / Not Sure
1	Almost guess	
2	Not Sure	
3	Sure	High/sure
4	Almost certain	
5	Certain	

The provisions for distinguishing students who guess the answer, do not know the concept, harbour a misconception, and know the concept are shown in Table 5 (Hasan et al., 1999).

Table 5

Criteria for Student Understanding

Answer Criteria	Low CRI (<2,5)	High CRI (>2,5)
Correct answer	Correct answer but low CRI means the student guessed the answer	Correct answer and high CRI mean good mastery of the concept
Wrong answer	The wrong answer and low CRI mean the student does not know the concept.	The wrong answer but high CRI means that there is a misconception.

The percentage of students who mastered concepts, lucky guesses, did not know the concept, and those who had misconceptions were calculated using the following formula:

$$P = \frac{F}{N} 100\% \quad (1)$$

Where P is the Percentage of students, F is the Frequency of students, and N is the total number of students.

In addition to classifying the types of students 'conceptual understanding, the level of students' misconceptions is also determined. The category for misconceptions can be seen in table 6 (Susanti & Effrita, 2021).

Table 6

Percentage Category of Misconceptions

Percentage of P (%)	Criteria
$0 \geq 30$	Low
$31 \geq 60$	Moderate
$61 \geq 100$	High

Results

Item Development

Suggestions for improvement from experts and practitioners and follow-up on recommendations for improving the two-tier diagnostic test are shown in Table 7.

Table 7

Suggestions and Follow-up to Improve the Two-Tier Diagnostic Test

No	Repair Aspect	Improvement Suggestions	Follow-Up Activities
1	Item indicator	There is an overlap between understanding the intended concept and cognitive knowledge.	Compiling indicator questions is focused on understanding the concept only.
2	Question arrangement	a. It's not good to use multiple choice questions using "except". b. The first letter of the answer to the multiple-choice questions should not be capitalized, except for the name. c. There are several descriptions of the symbols in the picture that are not consistent with the questions.	a. Changing the question editor to "which is not included". b. The first letter of the multiple-choice answer key is written in lower case. c. Synchronise between the description of the symbol in the picture and the problem.
3	Answer key	The answer key to question number 15 is not correct.	Fix the answer key to question number 15

The results of content validity analysis using the Aiken coefficient (V) are presented in Table 8.

Table 8

The Result of Aiken Coefficient

Item	∑	V	Criteria
1	11	0,92	High
2	10	0,83	High
3	9	0,75	Moderate
4	9	0,75	Moderate
5	11	0,92	High
6	10	0,83	High
7	10	0,83	High
8	12	1	High
9	11	0,92	High
10	9	0,75	Moderate
11	9	0,75	Moderate
12	11	0,92	High
13	12	1	High
14	10	0,83	High
15	9	0,75	Moderate
16	12	1	High
17	8	0,67	Moderate
18	12	1	High
19	11	0,92	High
20	12	1	High

Table 8 shows that all Aiken coefficients of items are in the high and moderate categories so that all items fulfill the content validity.

The validity of the construct was analyzed using the IRT method using the Quest program. The results of the item and case suitability analysis for the Rasch model are shown in Table 9.

Table 9

Summary of Item and Case Estimates

Fit Statistics	Item	Case
Reliability of estimate	0.71	0.38
Infit Mean Square	0.98	1.03
SD of Infit Mean Square	0.26	0.42
Outfit Mean Square	0.96	0.96
SD of Outfit Mean Square	0.53	0.55

Table 9 shows that the reliability of the item estimate is 0.71. Because the value of the reliability of the item estimate is more than 0.7 then the test instrument is reliable. Quest analysis results obtained that the average value of Infit Mean Square (Infit MNSQ) is 0.98 with a standard deviation of 0.26 and the average value of Outfit Mean Square is 0.96 with a standard deviation of 0.53. Based on the results of the analysis, it is obtained that the infit means square is in the range of 0.72-1.24 while the area of fit for the model is 0.77 -1.30. It can be said that there are some items that do not match the Rash model. The value of the outfit t is 0.92, and the area of acceptance for the outfit $t \leq 2$, so that the overall question items can be accepted or no questions are dropped.

The reliability of the case estimate is 0.38, which suggests that repetition of the test will produce unstable results. The higher the value the more convincing that the measurement is giving consistent results. Quest analysis results obtained that the average value of Infit Mean Square (Infit MNSQ) is 1.03 with a standard deviation of 0.42. Based on the results of the analysis, it is obtained that the infit

means square is 1.01-1.85 so some are not in the range 0.77 -1.33 so some test takers do not fit the Rasch Model.

The questions that can be answered by highly skilled test takers are all questions. Questions that are not able to be answered by medium-ability test takers are questions number 6, 12, and 14, and questions that can be answered by low-ability test takers are 1, 2, and 8. The estimated ability of test-takers to determine different power of the question item can be seen in Table 10 ((Bichi & Talib, 2018).

Table 10

Different Power of the Question Item

Estimate Value	Note	Item
$> +1{,}00$	High ability	6,12,14
$-1{,}00\ s.d + 1{,}00$	Moderate ability	3,4,5,6,7,9,10,11,13,15,16,17,18,19,20
$< -1{,}00$	Low ability	1,2,8

The advantage of IRT analysis is that it can represent the distribution of items that fit the Rasch model as shown in Figure 1. The items that match the Rasch model are in the range 0.77 -1.33.

Figure 1

The Plot Distribution of Items Matches to Rasch Model

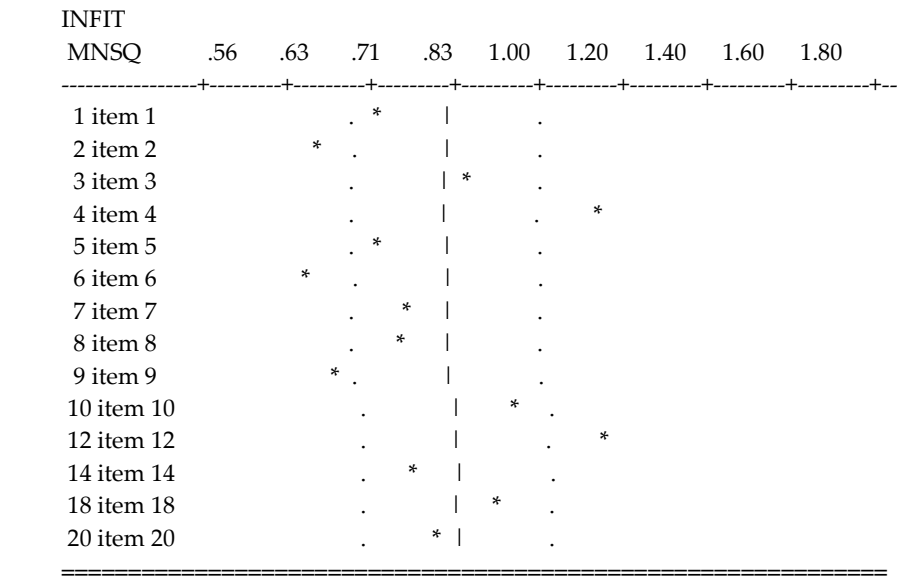


Figure 1 shows that there are items that are outside the range 0.77 -1.33 (it appears that there are items outside the line), namely items 1,2,5,6, and 9 means there are 5 items that don't fit the Rash model.

Based on the criteria in Table 3 as a reference for correcting items that do not meet the criteria. The quality of the items can be summarized in Table 11.

Table 11

Recapitulation of the Quality of Items

No	Infit MNSQ	*outfit t*	B	Quality
1	.82	.1	-2.42	Good
2	.71	-1.3	-.35	Quite good
3	1.06	.3	.65	Good
4	1.50	2.2	-.01	Not good
5	.82	.1	-2.42	Quite good
6	.68	-.9	1.42	Quite good
7	.90	-.5	.32	Good
8	.87	-.1	-1.64	Good
9	.74	-.9	-.71	Quite good
10	1.19	.9	.65	Good
11	0	0	0	Quite good
12	1.49	1.3	1.42	Quite good
13	0	0	0	Quite good
14	.88	-.2	1.42	Good
15	0	0	0	Quite good
16	0	0	0	Quite good
17	0	0	0	Quite good
18	1.13	.5	1.01	Good
19	0	0	0	Quite good
20	.99	.95	.65	Good

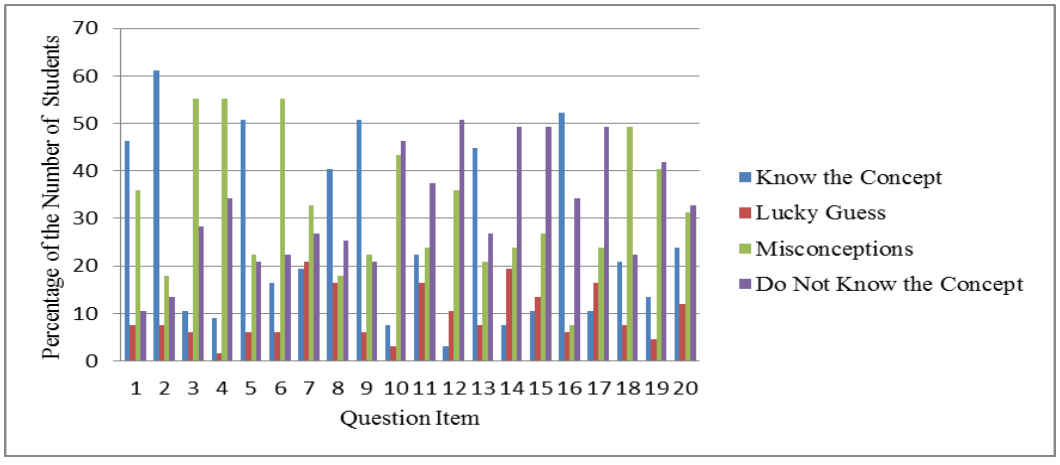
Table 11 shows that the number of questions in the good category is 8 items, 11 items are quite good, and only 1 item is not good (5%). Thus, the problem that needs to be fixed is only one question. The item that needs to be corrected is question number four.

Analysis of Students' Conceptual Understanding Trend

Figure 2 represents the results of identifying students' understanding of the concept of understanding the concept of light.

Figure 2

Students' Understanding of the Concept of Light



Students who know the concept are included in the high category only in item number 2. Students who understand the concept in the medium category are in items 1, 4, 8, 9, 13, and 15. The concepts in the other 13 items are understood by low-category students. The percentage of students who guessed the answer was low.

Misconceptions of students in the moderate category arose in questions 1,3, 5, 6, 7, 10, 12, 18, 19 and 20. Meanwhile, misconceptions of students in the other ten items are in a low category. Students who do not know the concept of the medium category are in questions number 4, 10, 11, 12, 14, 15, 16, 17, 19 and 20, while in the other 10 items, a low number of students do not know the concept.

The average CRI value for those who answered correctly and those who answered incorrectly is shown in Figure 3.

Figure 3

Graphic Comparison of Average CRI for Correct and False Answers

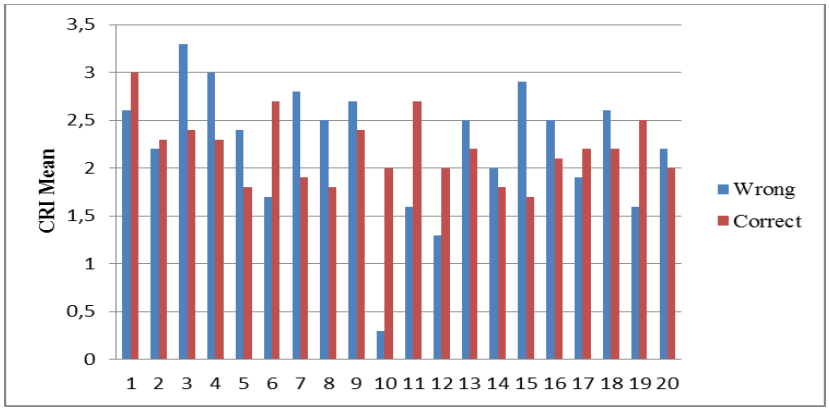


Figure 3 shows that students' misconceptions of the concept of light as a whole can be said to be moderate, namely 35%, and those who do not understand the concept with the high category are 65%. Meanwhile, students who understand the concept of light are in a low category, namely 15%.

The diagnostic results of students' understanding of the concept of light for each indicator are mapped into several subsections, namely light waves, reflection and refraction of light, critical angle, total internal reflection, and wave attenuation. The trend analysis of understanding the concept of each subsection of light can be explained as follows:

The concept of light waves consists of 4 questions, namely questions number 1 to number 4. The highest misconception occurs in the concept of light waves, namely the concept of light characteristics and the nature of the direction of light propagation against the wavefront (questions number 3 and 4). The second misconception that occurs within the moderate category is the concept of defining light as a wave (question number 1), in this case, students are still mistaken in distinguishing light as a wave and a particle. Most students already understand that light waves are a type of transverse wave (question number 2).

The concept of reflection and light refraction consists of 4 questions, namely questions number 5 to number 8. The misconception that occurs in this section is to draw inferences from the high category of diffuse reflection events (question number 6). Students experience a moderate category misconception on the concept of changing the number of light waves when refracted (question number 7). Most of the students already understood Snell's law and the concept of the direction of refraction in mediums that had different refractive index values (questions number 5 and 8). Students who do not understand the concept with the moderate category are on the concept of the direction of refraction at different refractive indexes (question number 8).

The concept of critical angle consists of 4 questions, namely questions number 9 to number 12. Students have misconceptions only about the critical angle definition indicator (question number 9). Many students do not understand the requirements for forming a critical angle and how to make the smallest critical angle value from the refractive index data presented (questions number 10 and 12).

The concept of total internal reflection consists of 3 questions, namely questions from number 13 to number 15. Most of the students did not know the concept of the requirements for total internal reflection and the meaning of the total reflection image representation (questions number 14 and 15).

The misconception about this concept is in the medium category (question number 15). Some students already understand the definition of a critical angle (question number 13).

The concept of wave attenuation consists of 5 questions, namely items number 16 to number 20. The misconception that occurs in wave attenuation is to provide examples of light scattering and absorption events in the moderate category (questions number 18 and 19). Eighty five percent of students of the students did not understand the mathematical equation of attenuated light (question number 17). They did not understand the concept of light dispersion in the medium category (question number 20). Most of the students already understood the definition of wave attenuation (question number 16).

Examples of answers from interviews with students on the characteristics of light include:

Question	:	*is light the same as ray?*
Student Answers	:	*Rays are the same as light*
Question	:	*State the properties of light that you know?*
Student Answers	:	*light can be reflected, light propagates straight, and light can be refracted.*
Question	:	*Does light need a medium to travel?*
Student Answers	:	*Yes*
Question	:	*Can light travel in a certain medium?*
Student Answers	:	*No*
Question	:	*What do you know about wavefronts?*
Student Answers	"	*The line goes in the direction of wave propagation*

Students consider the terms light and ray to be the same, even though these two things are different terms where light is a beam of light. Students only mention the nature of light as a wave even though light also has properties as a particle. Students understand that light can only propagate in a vacuum or does not require a medium, even though light can travel through certain materials such as water and glass. Twenty nine percent of students assume the wavefront is in the same direction as the wave propagation. A naive concept statement is to assume the direction of the wavefront is the same as the direction of the light.

The second example of student interview answers to the concept of reflection and refraction

Question	:	*What do you know about diffuse reflection?*
Student Answers	:	*Diffuse reflection is a reflection that occurs when a light source falls on an object with a rough surface so that light is reflected in all directions*
Question	:	*Does Snell's law of reflection still apply to diffuse reflection events? Why?*
Student Answers	:	*Does Snell's law of reflection still apply to diffuse reflection events? Why?*
Question	:	*Describe the characteristics of a ray of light refracted in a medium?*
Student Answers	:	*There is a deflection of the direction of light, where if it is towards a dense medium it is refracted towards the normal line and away from the normal line in a loose medium.*
Question	:	*If the angle of incidence is perpendicular to the medium, will the light be refracted? Why?*
Student Answers	:	*No, but the light is reflected back because there is no change in the direction of the light in the medium.*

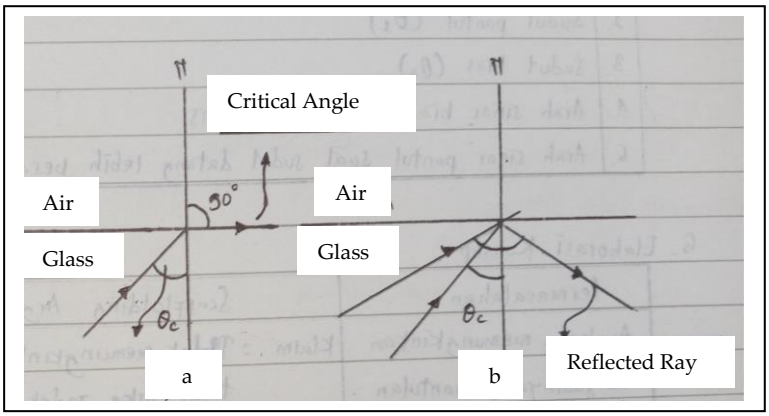
Eleven percent of students understand the definition of diffuse reflection, but they have not been able to infer that each segment of the field roughness has a normal line direction, so the law of reflection still applies. Students stated that there was no refraction when the incident ray was

perpendicular to the plane, according to them it was because there was no deflection of the refracted ray but it continued. So far, students understand that the characteristic of refraction only occurs when there is a deflection of direction, but actually, in these conditions, there is a refraction of the speed and wavelength values. This is shown by the refraction equation: $\frac{\sin\theta_2}{\sin\theta_1} = \frac{n_1}{n_2} = \frac{v_2}{v_1} = \frac{\lambda_1}{\lambda_2}$.

An example of a student's answer when asked to draw the critical angle and total internal reflection to verify the answers to questions 11 and 14 can be seen in Figure 4.

Figure 4

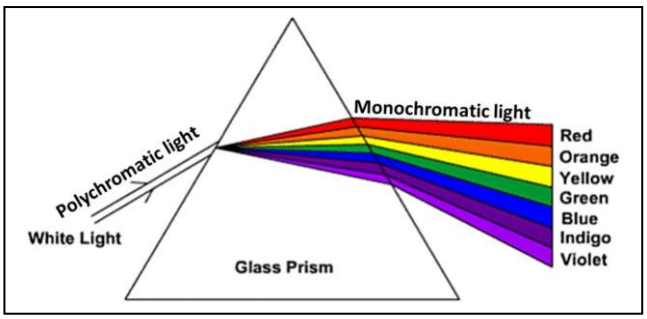
Sample Student' Answers about Critical Angle and Total Internal Reflection



When drawing a critical angle (Figure 4a), students do not draw an incident ray that coincides with the critical angle, but students provide a description of a ray that is parallel to the refractive planes of the two surfaces of the medium as a critical angle. This shows that 31% of students think that the critical angle is the refracted ray which is parallel to the medium boundary of the glass and air.
Figure 4(b) shows that students describe the total internal reflection without giving information about which is the incident ray and which is the critical angle ray. Eighty percent of students have not been able to provide a description of the requirements for total internal reflection both in terms of the ratio of the angle of incidence to the critical angle and the size of the refractive index of the medium of glass and air.

Figure 5

Refracted Monochromatic Ray by a Prism



Sample question number 20 regarding the most refracted monochromatic rays is shown in Figure 5. Student answers show that 67% of respondents agree that the difference in the direction of refraction of monochromatic light on a prism is determined by the speed of light. Thirty-three percent of respondents agree that each monochromatic light has a different frequency. Although most students believe that each monochromatic ray has a different speed when it enters the prism medium, they are inconsistent because few believe that the frequency of the monochromatic ray is different. Where the frequency is proportional to the speed because if the frequency of the monochromatic light

is high then the speed through the prism will also be high and the angle of deviation will be even greater.

Discussion

Twenty-nine of the students (n = 30) believe that the direction of the beam is parallel to the direction of the wavefront. The reason students think that the rays are in the direction of the wavefront is that the rays always point toward the wave propagation which is represented by a straight line. This is caused by the representation of light in refraction learning is depicted only in the form of a straight line without being accompanied by the direction of the wavefront misconceptions about the characteristics of the rays are caused by the language of communication, because misconceptions can be caused by humanistic thinking (Fakhruddin & Rahmi, 2012; Suparno, 2013).

Most students (89%, n = 30) state that the angle of incidence and the angle of reflection are not the same in an uneven plane. They think that Snell's law does not apply to uneven surfaces because they imagine the direction of the incident and reflected rays is random due to the surface of the uneven plane. Misconceptions about diffuse reflection are caused by their intuition that they assume that the normal line for the rough plane is the same as for the smooth plane. They do not realise that the normal on an uneven surface is not unidirectional. Because the plane is not flat, the position of the normal line for each segment of the plane is not the same. The directions of the angles of incidence and reflection of each plane segment are not the same, but each segment's angle value is the same as the angle of reflection. The results of this study are in line with the results of a study by Robertson et al., (2021) which showed that misconceptions are caused by intuitive formulations.

All students participating in the interview (100%) answered that there was no refraction when the incident ray was perpendicular to the plane but total reflection occurred. They answered that way because they already know in general that the characteristic of light refraction is characterised by the refraction of the direction of the refracted ray, so when the light is incident perpendicular to the plane it is considered that there is no refraction, even though when refraction occurs it will cause a refraction in the direction of propagation and refraction of the speed and wavelength values.

Eighty-five percent of students (n = 30) did not know the condition for the occurrence of a critical angle They are wrong in interpreting the representation of the critical angle, namely the angle of incident 90^{o}, they assume that the critical angle is the incident ray that is vertical to the plane.

Eighty percent of students did not understand the concept of total internal reflection. Students still have difficulty formulating the conditions for total internal reflection in the form of a mathematical equation. Students think that the condition for the occurrence of a critical angle is the same as the angle of total internal reflection. Misconceptions of total internal reflection like this are caused by associative thinking, namely, the concept of total internal reflection is associated with a critical angle (Fakhruddin & Rahmi, 2012; Suparno, 2013).

Ninety percent of students do not understand the meaning of the mathematical equation of wave attenuation as many as 33% of students understand the concept of absorption and scattering of light but they do not understand how to formulate it in the form of a mathematical equation. Students have difficulty formulating their own mathematical equations in learning (Agustyaningrum et al., 2021).

Students' understanding of the concept of light needs to be improved, especially with respect to the following: (1) The ray is in the same direction as the wavefront; (2) Snell's law does not apply to diffuse reflection; (3) There is no refraction of the wavelength and velocity values when the refraction occurs at an angle perpendicular to the plane; (4) the critical angle is the incident ray that is vertical to the plane; and (5) the total internal reflection is associated with the critical angle. The results of a similar study by Susanti and Effrita (2021) indicated that students believed that light cannot reach distant places, but distant observers can see light source; that the distance between candles during the day is shorter than at night; and that the colour of an object is not determined by the colour of the light hitting the object

Most of the students also did not understand the light concept as a prerequisite concept for teaching fibre optics, especially regarding the concept of the direction of refraction at different refractive indexes, the conditions for a critical angle and total internal reflection, and the meaning of the mathematical equation of attenuating light. They have difficulty understanding the sub-concepts because they do not understand the physical meaning of mathematical equations of concepts and they have difficulty formulating physical concepts in the form of mathematical equations. Combining symbols and structures of mathematical knowledge in physics is important so that every number, variable, and mathematical equation can be used to interpret the physical meaning and relationship (Bing & Edward, 2007). The results of research by Kereh et al (2014) show that there is a high correlation between the mastery of basic mathematics material and the introductory material of core physics. Many students have difficulty solving physics problems, one of which is not being able to apply mathematics to solving physics problems (Hidayatulloh, 2020). The process of solving problems by students combining physics concepts and mathematical reasoning depends on how well these students correctly associate mathematical symbols with physics concepts (Rahmah, 2021). The causes of students' failure to solve physics problems using mathematics are (1) students fail to apply the same reasoning with complex numbers; (2) students rejecting their correct mathematical reasoning in favor of wrong intuitive reasoning; and (3) student's failure to use their knowledge (Tuminaro & Edward, 2005).

Student's difficulties in understanding the concept of light are influenced by internal and external factors. Internal factors that cause students' learning difficulties in understanding concepts are factors of interest, aptitude, and intelligence (Novita et al., 218). External factors cause student learning difficulties in the form of school facilities, teachers, infrastructure, and student activities (Haqiqi, 2018). The learning model and understanding of the theory of tackling student learning difficulties are needed. There are three kinds of theoretical frameworks for overcoming student learning difficulties (Docktor & Mestre, 2014), namely: First, the theory of misconceptions states that the difficulty of students mastering scientific concepts is because students already have misconceptions about the concept. Second, resource theory or knowledge in pieces states that students have difficulties in applying concepts to solve problems. Third, the ontological category theory states that students' difficulties are caused by students' mistakes in making ontological categories of a concept. The steps that must be taken by the teacher in overcoming learning difficulties are first, analyzing the results of the diagnosis. Second, identify and determine certain skill areas that require improvement. Third, compiling a remedial teaching programme (Nuraeni & Syihabuddin, 2020).

Conclusion and Implications

A two-tier instrument for diagnosing light concepts. The results of the content validity using the Aiken coefficient showed that all items met the content validity. The construct validity using the IRT shows that all questions were in the valid category except for only one question that required revision.

Students' understanding of the concept of light needs to be improved are (1) The ray is in the same direction as the wavefront; (2) Snell's law does not apply to diffuse reflection; (3) There is no refraction of the wavelength and velocity values when the refraction occurs at an angle perpendicular to the plane; (4) the critical angle is the incident ray that is vertical to the plane; and (5) the total internal reflection is associated with the critical angle.

The results of this study can be used by practitioners to diagnose students' initial concepts on light, whether they understand the concept or still have misconceptions. Educators are expected to diagnose students' initial abilities as a reference for compiling teaching materials and selecting learning models. For future researchers, this research can be used as a basis for developing students' initial concept diagnostic tests on other materials.

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Appendix

Instructions for Answering Questions

a. Choose the answer that you think is the most correct by choosing A, B, C, D, or E.
b. Choose your level of confidence in your answer by checking:

0 = Guessed answer
1 = Almost a guess
2 = Not sure
3 = Sure
4 = Almost certain
5 = Certain

Question

1. a. What is not a wave nature of light is...
   A. reflected
   B. refracted
   C. polarized
   D. streamed in the form of photons
   E. refracted
1. b Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

2. a. Light is a type of wave….
   A. longitudinal
   B. mechanical
   C. seismic
   D. stationary
   E. transverse

2. b Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

3. a. Pay attention to the statement below!
   (1) Rays propagate parallel to the wavefront
   (2) Rays propagate straight on homogeneous media
   (3) Rays can be reflected and refracted
   (4) The ray path is reversible.
   The exact statement regarding the characteristics of the rays is….
   A. (1), (2), (3), and (4)
   B. (1), (2), and (3)
   C. (1), (3), and (4)
   D. (2), (3), and (4)
   E. (1), (3), and (4)

3. b Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

4. a. The direction of the rays in Figure 4 is….

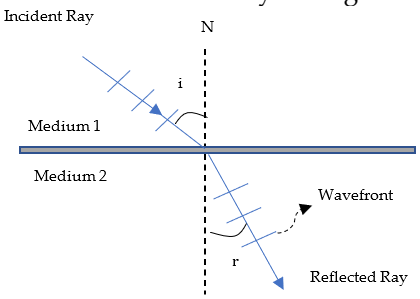


Figure 4. The ray spreads from medium 1 to medium 2
A. Parallel to the wavefront
B. Parallel to the normal
C. Perpendicular to the normal
D. Perpendicular to the reflected plane
E. Perpendicular to the wavefront

4. b. Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

5. a. The angle of incidence is equal to the angle of reflection, where the incident rays and reflected rays lie on a plane, which is the law of ....
   A. Fresnel
   B. Fermat
   C. Snell
   D. Maxwell
   E. Brewster

5. b. Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

6. a. The incorrect statement about the reflection in Figure 6 is….

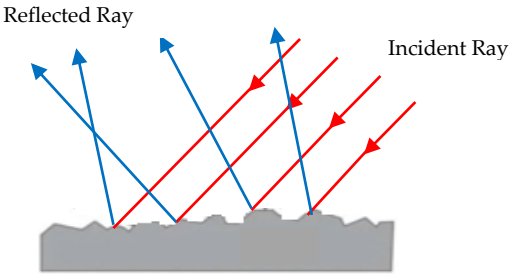


Figure 6. Diffuse reflection

A. The reflected beam is irregular
B. Snell law of reflection does not apply
C. The eye will find it easier to see objects
D. The surface of the reflected plane is uneven
E. This is called diffuse reflection

6. b. Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

7. a. Look at Figure 7! The correct statement with the conditions of wavelength, velocity, and frequency after entering the second medium is….

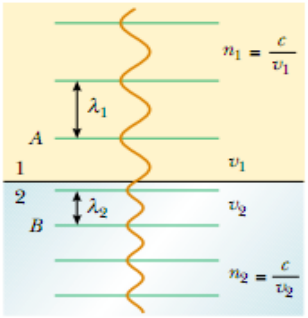


Figure 7. Wave propagation from medium to 1 to medium to 2.

A. Fixed wavelength, changing speed, and face frequency
B. Changing wavelength, constant speed, and face frequency
C. Changing wavelength, changing speed, and face frequency
D. Fixed wavelength, constant velocity, and changing frequency
E. The wavelength, wave velocity, and frequency are fixed respectively

7. b. Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

8. a. Figure 8 illustrates the law of….

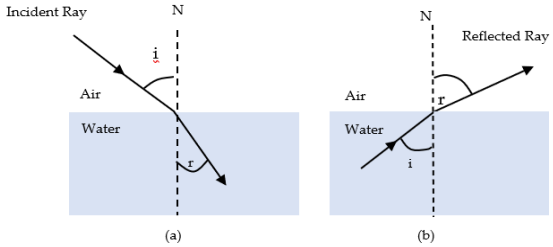


Figure 8. (a) ray coming from the air medium to water, (b) ray coming from the water to the air

A. dispersion
B. total internal reflection
C. refraction
D. critical angle
E. polarization

8. b. Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

9. a. The angle of incidence which produces a refractive angle $90^o$is called ...

A. Brewster's corner
B. Angle of scattering
C. Angle of deviation
D. Polarization angle
E. The critical angle

9. b. Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

10. a. Which is not a condition for the occurrence of a critical angle is….

A. The rays are refracted parallel to the surface boundaries of the two mediums
B. The angle of the incident beam is equal to the critical angle
C. The angle of incidence is greater than the critical angle
D. The angle of refraction of the incident rays is
E. The rays come from the dense medium to the tenuous medium

10. b. Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

11. a. The critical angle in Figure 11 is shown by ...

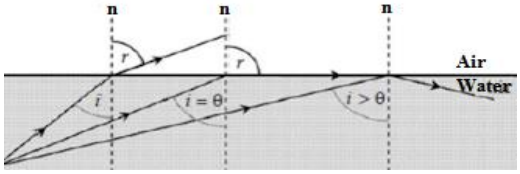


Figure 11. Ray propagation from dense medium to tenuous medium

A. i
B. r
C. $i = \theta$
D. $i > \theta$
E. i and r

11. b. Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

12. a. Based on table 12, the smallest critical angle will be obtained if the rays come from….

Table 12. Refractive Index of Materials

Material	Refractive Index
Air	1
Water	1,33
Silica	1,46
Glass	1,52
Diamond	2,42

A. Water to air
B. Silica to air
C. Glass to air
D. Diamond to air
E. Silica to water

12. b Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

13. a. If the angle of incidence is enlarged to exceed the critical angle then the ray will….
A. refracted
B. polarized
C. partially refracted and partly reflected
D. dispersed into monochromatic rays
E. perfectly reflected in the medium

13. b. Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

14. a. The cause of total internal reflection is….
A. Differences in the refractive index of the medium ($n_1 \neq n_2$) and $i > \theta$
B. Differences in the refractive index of the medium ($n_1 \neq n_2$) and $i = \theta$
C. Differences in the refractive index of the medium ($n_1 \neq n_2$) and $i < \theta$
D. Differences in the refractive index of the medium ($n_1 = n_2$) and $i > \theta$
E. Differences in the refractive index of the medium ($n_1 = n_2$) and $i = \theta$

14. b Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

15. a. Look at Figure 15! The mathematical equation for the refractive index for total internal Reflection to occur is….

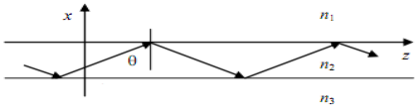


Figure 15. Total internal reflection on waveguide

A. $n_1 > n_2$
B. $n_2 > n_1 \; dan \; n_2 > n_3$
C. $n_3 > n_2$
D. $n_3 = n_2$
E. $n_1 = n_2$

15. b Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

16. a. Wave attenuation is….
    A. increasing wave amplitude
    B. reduced wave period
    C. symptoms of transmission signal attenuation
    D. decreased frequency of the wave
    E. decreasing wavelength

16. b. Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

17. a. Electromagnetic waves propagate in a conductive medium in the direction of the axis with the equation

$$E = E_0 e^{-\frac{z}{d}} e^{i(kz-\omega t)}$$

The value indicates that the wave amplitude in the conductive medium will experience ...
    A. diffraction exponentially
    B. exponential attenuation
    C. polarization exponentially
    D. refraction exponentially
    E. dispersion exponentially

17. b. Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

18. a. The sky looks blue is an example of an event….
    A. scattering
    B. reflection
    C. dispersion
    D. diffraction
    E. interference

18. b. Your level of confidence in your answer is….

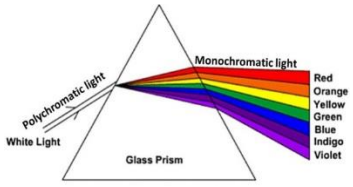
Guessed answer	0	1	2	3	4	5	Very certain

19. a. Examples of light absorption events are….
    A. Light is scattered by irregular fields
    B. The pencil looks bent when put in the water
    C. Light is flexed by a narrow gap
    D. Light is described when a rainbow occurs
    E. The skin feels warm when exposed to the sun

19. b. Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain

20. a. The most refracted monochromatic rays in Figure 20 are….



    A. Violet
    B. Blue
    C. Red
    D. Orange
    E. Green

20. b Your level of confidence in your answer is….

Guessed answer	0	1	2	3	4	5	Very certain