Article Diagnostic Difficulties and Misconceptions of Light Refraction: A Need Analysis Learning Abstract Concepts Using PhET Simulation

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ABSTRACT
This study aims to diagnose difficulties and misconceptions of light refraction. This research was conducted by qualitative design. The sample consists of 84 students who were taken from the second semester of physics education at 5 universities in Indonesia. Trend data on understanding the concept of light refraction were collected using a three-tier test. Difficulties and naive reasons about light refraction were collected by interview. Students' misconceptions are measured by the Certainty Response Index (CRI) analysis technique. The results showed that although the concepts of light refraction have been studied by students, they still have difficulty answering questions about light refraction. Students' misconceptions occur in the aspect of the direction of wave propagation perpendicular to the wavefront with a high category and misconceptions on the value of wave physical quantities refraction in the medium category. The concept of wavefronts and the value of wave physical quantities is abstract, so it is necessary to consider learning to use PhET Simulation to visualize the concept so that it is easily understood by students.

Keywords: *Diagnostic initial concepts, Misconception, Light refraction, PhET simulation.*

1. INTRODUCTION

Diagnostics of students' initial concepts need to be done before learning begins as a reference for designing teaching materials that suit the needs of students. Low initial concept understanding causes students to have difficulty connecting other concepts related to the concept being studied [1]. For example, even though there is an increase in the average proportion of mastery of the refraction of light concept, generally students still have difficulty drawing the angle of incidence, direction of refraction, and the position of refraction for the arrangement of two mediums [2].

Concepts of light refraction are basic and yet important content in physics education. Students need to gain this scientific concept properly to understand related and advanced physics concepts in the future. Students have significant misconceptions about the direction of light refraction, how light is refracted and how to determine its position from an image [3]. Most students still lacked knowledge in using a ray diagram to explain refraction phenomena. The two main concepts that most of the students missed were the propagation of light from the object to the observer's eyes and the law of refraction [4].

In recent years, to promote students' conceptual change, several researchers have attempted to develop instructional materials and research for teaching of physics concepts: for example, multiple representations [5], the simulation-based inquiry [6,7], the PhET simulation [8,9]. Methods and media that have been carried out by previous researchers as a consideration for choosing and modifying the fit learning model to improve students' understanding of concepts.

Instruments that have been used by previous studies to measure misconceptions are the transformation of the open-ended questions into multiple-choice questions [10], two-tier test [11], three-tier test [12], and four-tier test [13]. In this study, the researcher used a three-tier test and interview.

The theoretical parameters associated with light, such as its wave front, speed, wavelength, frequency, and intensity are abstract concepts. Therefore, this study aims to diagnose trends in understanding the concept of ray characteristics and physical quantities of waves that are constant and change when light propagates through the

medium. In addition, this study will analyze the need for Physics Education and Technology (PhET) to visualize the abstract concept so that it is easily understood by students. This PhET simulation media was developed to assist students in understanding physics concepts visually by using dynamic graphics that can explicitly animate the visual and conceptual models [13].

2. METHODS

2.1. Research Design

This research was conducted by qualitative design. The survey method uses a three-tier test. Interview method uses to collect the qualitative data from participants. Therefore, this design gave the researcher the opportunity to deeply understand the causes and factors difficulties and misconceptions of students.

2.2. Participants

The sample consists of 84 students who were taken from the second semester of physics education at 5 universities in Indonesia (IAIN Palangka Raya, University of Hamzanwadi Selong, UIN Mataram, UIN Raden Intan Lampung, University of Muhammadiyah Metro Lampung). The sample was selected by cluster random sampling.

2.3. Data Sources and Procedures

Factors that cause students to have difficulty in answering questions and naive reasons to support answers are collected through interview. Trend data for understanding the concept of ray characteristics and refraction were collected using a three-tier test. After students answered the three-tier questions, they were then interviewed using open-ended questions to explore the reasons for difficulties in understanding concepts and exploring naive reason about light refraction.

2.4. Data Analysis

Students' misconceptions are analyzed by 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 [14]. The CRI technique can not only identify student misconceptions but also can distinguish students who know concepts and students who do not know the concept. CRI is usually based on a scale in Table 1[15]. The provisions for distinguishing students who guess the answer, do not know the concept, misconception, and know the concept are shown in Table 2[15].

Table 1. Certainty response index assessment criteria

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

Table 2. Justification reference of concept understanding trend

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	Wrong answer and low CRI mean you don't know the concept	The wrong answer but high CRI means that there is a misconception

In addition to classifying the types of students' conceptual understanding, the level of students' misconceptions is also determined. The criteria for misconceptions in Table 3.

Table 3. Percentage category of misconceptions

Percentage (P)	Criteria
61% ≤ P ≤ 100%	High
31% ≤ P ≤ 60%	Moderate
0% ≤ P ≤ 30%	Low

3. RESULTS AND DISCUSSION

3.1. The Concept of Ray Characteristics

Trends in understanding concepts are categorized in the form of knowledge of the concept, lucky guess, misconception, and don't know the concept. The diagnostic results of the trend of students' understanding of the concept of light characteristics in Table 4.

Table 4. The trend of understanding the concept of ray characteristics

Ray Characteristics	Percentage	Criteria
Know the Concept	10.45	low
Lucky Guess	5.97	low
Misconceptions	55.22	high
Do Not Know the Concept	28.36	low

Table 4 shows that students still experience misconceptions in the high category on the concept of rays propagating perpendicular to the wavefront. They assumed that light propagated parallel to the wavefront. 50% of students stated that light is the direction of the wavefront. The reason for students who think that the rays are in the direction of the wavefront is because the rays always point in the direction of the wave propagation which is represented by a straight line to the wavefront. The questions used to test the trend of understanding the concept of the characteristics of light is:

Question: Pay attention to the statement below!

(1) Ray travels parallel to the wavefront
(2) Ray propagates in a straight-line inhomogeneous media and is curved in heterogeneous media.
(3) Ray can be reflected and refracted
(4) The ray path can be reversed.

a. The correct statement regarding the characteristics of light 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)

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

0	1	2	3	4	5
Totally guess	Almost guess	Not Sure	Sure	Almost certain	Cer tain

c. Explain the reasons to support your answer!

The answer key to the question is D. The number of students who answered correctly was 14.5%. Students who chose answers A (19.3%), B (36.1%), C (20.5%) and E (9.6%). Answers A, B, C, and E are wrong because the answer key contains a statement that the rays propagate parallel to the wavefront. The reason why students have difficulty answering questions about the characteristics of light is that they have never studied the concept in question (17.6%), the concept in question has been studied but has not been understood (82.4%) and did not understand the meaning of the question (5.9%).

Trends in the student's naive explanation of the characteristics of light include: (1) The characteristics of ray are that direction of the rays is parallel to the wavefront, light travels in a straight line, and light can be refracted. In this explanation, students equate the terms light and ray. Though these two things are different terms where the ray is a beam of light. (2) Because it does not require a medium in its propagation. So, ray doesn't need a medium to propagate. This explanation shows students understand that ray can only propagate in a vacuum or does not require a medium, whereas ray can propagate on certain materials such as water and glass.

3.2. The refraction of light concept

The results of the diagnostic trend of students' understanding of the concept of light refraction in Table 5.

Table 5. The trend of understanding the concept of light refraction

Refraction	Percentage	Criteria
Know the Concept	19.4	low
Lucky Guess	20.9	low
Misconceptions	32.84	medium
Do Not Know the Concept	26.87	low

Table 5 shows that students still experience misconceptions in the moderate category on the concept of a constant physical quantity of light waves when traveling on different refractive index mediums. The questions used to test the trend of understanding the concept of the refraction of the magnitude of the light wave is:

Question: Look at Figure 1!

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

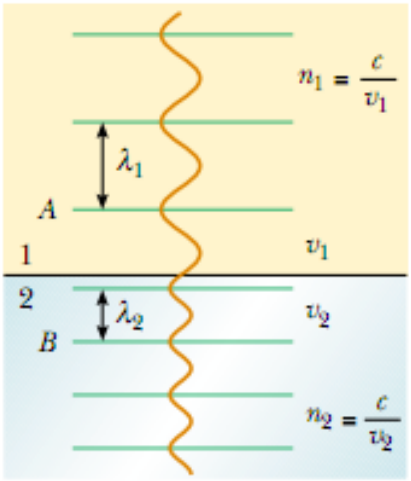

Figure 1 Wave propagation from the first medium to the second medium.

A. The constant wavelength, changing speed, and frequency is constant

B. Changing wavelength, constant speed, and frequency is constant
C. The wavelength changes, the speed changes, and the frequency is constant
D. The fixed wavelength, constant speed, and changing frequency
E. The wavelength, wave speed, and frequency are each constant

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

0	1	2	3	4	5
Totally guess	Almost guess	Not Sure	Sure	Almost certain	Certain

c. Explain the reasons to support your answer!

The answer key to the question is C. The number of students who answered correctly, namely changing the wavelength, changing speed, and face frequency was 41%. The trends of incorrect answers are (1) Changing wavelength, fixed speed, and frequency of contact, 24.1%, (2) Fixed wavelength, changing speed, and frequency of contact 16.9%, (3) Fixed wavelength, fixed speed, and changing frequency 16.9%, and (4) Wavelength, wave speed, and frequency remain 1.2% each. The reason students have difficulty answering questions about the wave magnitude that changes when entering the medium is that they have never studied the concept in question 37.3%, the concept asked has been studied but has not been understood 59.7%, does not understand the meaning of the question 10.4%.

The trend of students' naive reasons for the constant physical quantity of light waves when passing through a medium with different refractive indices include:

a. Because the higher the value of a refracting medium, the slower the wave speed and the larger the wavelength. This statement is not correct, it should be if the wave speed is high, the wavelength value is getting shorter.

b. If the wave propagates perpendicular to the plane, then there is no refraction of the wave because refraction occurs when there is a deflection of the direction of the ray. This statement is not true because it assumes that refraction only occurs when the ray is bent. They answered that because they already knew in general that the characteristic of light refraction is characterized by the bending of the refracted ray direction so that when the light comes perpendicular to the plane, there is no refraction, but a total reflection. Whereas when refraction occurs, it will cause refraction of the direction of propagation and value of physical quantity. When studying refraction, they are used to using the Snell's law equation, so that what comes to their mind is that if the angle of incidence and angle of refraction is zero, there will be no refraction of the direction of the rays. Changes in the value of the physical quantity of waves can be proven by the equation $\frac{sinsin\,\theta_2}{sinsin\,\theta_1} = \frac{n_1}{n_2} = \frac{v_2}{v_1} = \frac{\lambda_1}{\lambda_2}$.

3.3. Discussion

Students' misconceptions that the direction of the rays is parallel to the wavefront is a misconception due to incomplete or wrong reasoning. The students' misconceptions which think that the refraction of light is only marked by a change in the direction of the propagation of light is caused by wrong intuition and the language of communication which thinks refraction is identical to the deflection of the direction of the rays. The results of this study are in line with the results of research by Robertson et al., (2021) showing that misconceptions in force are caused by intuitive formulations [17]. Misconceptions originating from students can be collected in several ways, namely initial knowledge or preconceptions or prior knowledge, associative thinking of students, humanistic thinking, incomplete or wrong reasoning, wrong intuition, stages of student cognitive development, student ability, and student interest [18].

Students claim that rays are part of the light that propagates in the form of straight lines, but they do not understand that the concept of rays is a representation of the direction of wave propagation, where the direction of the rays is always perpendicular to the light wavefront. This is because the representation of rays in refraction learning is depicted only in the form of a straight line without being accompanied by a wavefront image. Likewise, the refraction of physical quantity values when entering various mediums is an abstract concept that requires visualization in learning. Therefore, to teach the concept of ray characteristics and refraction, it is necessary to visualize the wavefront representation and refraction of the physical value of the wave magnitude using PhET simulation. Science teachers should integrate appropriate technology into instruction to support identifying and addressing specific student misconceptions [18].

PhET Simulation can help introduce a new topic, build concepts or skills, reinforce ideas, and provide final review and reflection. The PhET simulation is designed to facilitate students to construct their conceptual understanding through exploration. The most effective simulation when students' exploration is guided by the instructor, homework, lab, and recitation activities using a guided inquiry [8]. By dragging the light intensity meter out of the box, we can measure the intensity values of refracted, reflected, and incident rays, as shown in Figure 2.

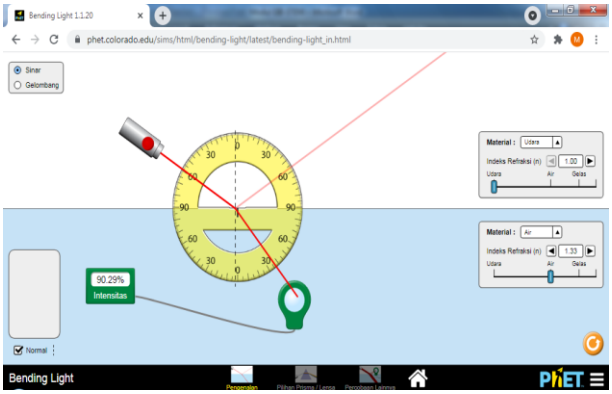

Figure 2 Simulation of light intensity measurement in https://phet.colorado.edu/in/.

Through PhET simulation, the bending light in Figure 2 can also be used to visualize the direction of the angle of incidence, from these changes, produces a different angle of refraction. In addition, the condition of the refracting medium can be changed according to needs. Through this PhET simulation, it has the potential to overcome students' misconceptions about the refraction of the value of the physical wave quantity.

The advantages of using PhET simulation media in the learning process are (a) Presenting information about processes or physics concepts that are quite complex; (b) It is independent because it provides convenience and completeness of content so that users can use it without the guidance of others; (c) Attract the attention of students to increase motivation to learn in the classroom; (d) PhET simulation can be used offline either in class or at home [20]. (e) PhET simulation can be used to do "experiments" that are impossible to do otherwise; and (f) PhET simulation can show the invisible and explicitly connect multiple representations [21]. The weakness of PhET simulation media are (a) The success of a learning process depends on the independence of students; and (b) Depending on the number of computer facilities provided by the school [22].

4. CONCLUSION

Although the concepts of light and refraction have been studied by students, they still have difficulty answering questions about the characteristics of light and the physical quantities of waves that are constant and change when refraction occurs in the medium. Students' misconceptions occur in the aspect of the direction of wave propagation perpendicular to the wavefront with a high category and misconceptions on the refraction of wave magnitude values in the medium category. The concept of wavefronts and the value of wave physical quantities is abstract, so it is necessary to consider learning to use PhET Simulation to visualize the concept so that it is easily understood by students.

AUTHORS' CONTRIBUTIONS

Muhammad Nasir: collecting data and drafting manuscript. Cari: conceptualization of manuscript. Widha Sunarno and Fitria Rahmawati: Reviewing and editing manuscript.

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