Surveying Thai freshmen science students' background knowledge of basic properties of laser beam

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Abstract

Nowadays, lasers play a key role in human life. Some lasers are simply used in classrooms while some are used in a nuclear reactor. Lasers are essential components in many advanced instruments such as Atomic Mass Microscope (AFM), Elipsometer and Spectroscopy that are generally used by science students in their laboratories and senior projects. In order to use laser properly, it is important that students must have background knowledge in basic properties of the laser beam. To investigate students' background knowledge, the five open-ended questions, corresponding to the five basic essential properties of laser beam including directionality, beam divergence, intensity, speed and monochromaticity, were designed and administered to 271 Thai freshmen science students. These students participated in Introductory Physics course in the second semester of academic year 2010. The questions were given to the students before the instruction on the Optics topic was begun because the results would be used as the guidelines in teaching about laser in this course. The students' responses were classified into five levels of understanding. The results revealed that students had the best background in the directionality while the beam divergence was the topic which students had the weakest background. However, the number of students who could answered the questions correctly were lower than 60% in all conceptual area.

Keywords: Alternative conceptions, Properties of laser beam, Understanding level.

Resumen

Hoy en día, el láser juega un papel clave en la vida humana. Algunos láseres se utilizan simplemente en salones de clase mientras otros son usados en un reactor nuclear. Los láseres son componentes esenciales en muchos instrumentos avanzados como Microscopio de Masa Atómica (AFM), Elipsómetro y Espectroscopía que son usados generalmente por los estudiantes de ciencias en sus laboratorios y proyectos superiores. Con el fin de utilizar adecuadamente el láser, esto es importante que los estudiantes que los estudiantes tengan más conocimiento a fondo en las propiedades básicas del rayo láser. Para investigar el conocimiento de los estudiantes a fondo, las cinco preguntas abiertas-últimas, correspondiendo a las cinco propiedades básicas esenciales del rayo láser incluyendo la direccionalidad, la divergencia del rayo, la intensidad, velocidad y monocromático, donde se han diseñado y administrado a 271 estudiantes de primer año de ciencias de Tailandia. Estos estudiantes participaron en el curso Introductorio de Física en el segundo semestre del año académico 2010. Las preguntas que se les dieron a los estudiantes antes de la instrucción sobre el tema de Óptica fueron debido a que los resultados podrían ser usados como directrices en la enseñanza acerca del láser en este curso. Las respuestas de los estudiantes fueron clasificados en cinco niveles de comprensión. Los resultados revelaron que los estudiantes tuvieron la mejor experiencia en la direccionalidad mientras que la divergencia del haz fue el tema que los estudiantes más débiles tuvieron de fondo. Sin embargo, el número de estudiantes que podrían responder a las preguntas correctamente fueron más bajos de 60% en toda el área conceptual.

Palabras clave: Concepciones alternativas, Propiedades de rayo láser, Nivel de comprensión.

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I. INTRODUCTION

Lasers have been well-known since 1960's and have played a central role in many fields of applications, for instance, medicine, industry, military, metrology, scientific research, and education [1, 2, 3, 4]. It has fascinated many people due to its amazing properties such as brightness and long length collimated light. Students are familiar with laser not only in

the lecture or textbooks but also in real life [5, 6, 7, 8]. Many toys integrated with laser are sold in the markets. Lasers have been appeared in many movies such as Star Wars, Star Trek, Resident Evil and James Bond 007 for a long time. They are mostly used as fighting weapons and defensive systems. Another well known example would be the laser pointer that is a very common tool used in the classrooms.

In Introductory Physics course, lasers usually appear in the Optics section as one kind of light sources. Laser beams have some properties similar to the general light and can give obvious observation, they are then usually used to demonstrate the properties of light such as reflection, refraction, diffraction and interference [9, 10, 11, 12, 13, 14, 15, 16, 17, 18]. On the other hand, laser beams also have unique properties that contrast from other lights. The differences arise from the emission process of light and the structure of laser. These are usually discussed in the Atomic Physics section. However, lecturers mainly focus on the microscopic view such as atomic radiation and lasing process but do not emphasize on the properties of laser light [5, 6, 7, 19, 20, 21, 22, 23].

There are many properties of laser beam that students should know such as laser mode, beam profile, pulse duration etc. Initially, only five basic essential properties - directionality, beam divergence, intensity, speed and monochromaticity – were selected to study since these are basic properties often mentioned in general physics textbook. They are vital for freshmen students' background and can obviously be observed in the classroom. The followings are the ideas about these five properties:

- **The Directionality:** Laser beam is highly directional. Many students are familiar with this because lasers are generally used as an accurate pointing tool. In optics, laser is usually used to demonstrate some geometrical optics phenomena such as the positioning of image formation from mirror and lens, the refraction of light and refraction angle, etc.
- **The Beam Divergence:** Laser beam diverges with a very small angle. Many students believed that laser beam has a parallel rod shape without diverging. In order to understand why some optical techniques such as beam collimation are required in the experiments, students need to understand this inevitable property.
- **The Intensity:** The intensity of the laser beam is decreased along the axial distance. The tendency of decreasing is different from an isotropic light. Many students believed that a laser beam propagates without dropping its intensity. Understanding this topic is important for student in order to think about the limitation of using laser for a far distance.
- **The Speed of Laser Light:** Laser beam propagates in air with the speed c, the same as other electromagnetic waves. Many students believed that laser light has a different speed from general light due to some parameters such as intensity and frequency. Understanding the speed of laser light is important for student in order to understand some laser applications such as laser velocimeter and laser range finder.
- **The monochromaticity:** Laser emits light with a narrow spectral width. It is sometimes called monochromatic light. Many students believed that light emitted from a laser is an ideal monochromatic light since it has a narrower spectral width than other light sources. Refraction, interference and diffraction can be observed clearly using monochromatic lights.

To improve students' understanding, the evaluation of students' background knowledge in these topics is necessary. It also provides benefit in preparing the course. This study concerns students' conceptions received from the open-ended investigations. Following is the research question of this study

"**What is Thai freshmen science students' background knowledge in five properties of laser beam: directionality, beam divergence, intensity, speed and monochromaticity?**"

II. RESEARCH METHOD

This study is designed to collect students' responses to the open-ended questions to determine freshmen science students' understanding levels and to elicit students' alternative conceptions.

A. Participants

The participants were 271 freshmen science students from a university in Bangkok, Thailand. The test was applied in the second semester of academic year 2010, before learning Optics in the Introductory Physics course. The students had already studied the topic of laser in their high school physics course in compliance with the compulsory Thai national physics curriculum by IPST (Institute of Promotion of Teaching Science and Technology); the government organization developing science and mathematics curricular in Thailand. The laser topic was a subtopic in Atomic Physics which is normally taught in grade 12. The contents include stimulated emission, the principle of laser operations, examples of lasers, directionality of laser, monochromaticity, coherence, brightness, and applications of laser.

B. The open-ended test

The test was firstly designed in Thai language. It was developed from questions appearing in many well-known physics textbooks [24, 25, 26, 27, 28, 29]. It was revised twice after administering to five graduate physics students and five graduate physics education students. After that, the validity of the test was collated by five college physics professors. All of them had at least ten year experiences in teaching physics and also have done advanced researches with laser. They were invited to judge the item objective congruence. Each expert assessed if each item correlates

with the stated purpose of the item, by marking agree (+1 point), in which the item and its purpose correlated, not sure (0 point), or disagree (-1 point), in which the item and its purpose did not correlate. Then the Index of the Item-Objective Congruence (IOC index) was calculated to indicate the validity of the test. Turner and Carlson (2003) suggested that a general accepted value might be a minimum of 0.75 [30]. The calculated value of IOC index of our test is 0.88 which is greater than the accepted value. We also modified our questions based on experts' suggestions.

TABLE I. Scope of the question in each topic.

Topic	*Scope of the question*	*Question*
Directionality	Determine the position(s) that the laser light will propagate to.	1
Divergence	Notify the relationship between the distance and the size of a laser beam.	2
Intensity	Notify the relationship between the distance and the intensity of light emitted from a light bulb.	3.1
	Notify the relationship between the distance and the intensity of a laser.	3.2
	Compare the trend of the light intensity at any distance between laser and light bulb.	3.3
Speed of light	Compare the speed of light from laser to other light sources.	4
Monochro-maticity	Identify the light source from the dispersion phenomenon.	5

The test consists of 5 open-ended questions which covers five properties of a laser beam: the directionality, divergence, intensity, speed, and monochromaticity. The scope of the questions is presented in Table I. Questions in the directionality, divergence, speed, and monochromaticity asked students to provide explanation to their answers. Question in the intensity was designed differently because students did not have enough background knowledge corresponding to the laser mode to explain the intensity of the laser beam. Consequently, the question was separated to three consecutive subquestions. The first subquestion probed basic concept in the intensity of an isotropic light by asking students to compare the intensity of light emitted from a light bulb at different distances. The second subquestion asked students to compare the intensity between light emitted from a light bulb and light emitted from a laser. The last subquestion asked students to exhibit their ideas about the intensity of laser beam at different distances. All questions are presented in the appendix.

C. Data Analysis

Several researchers applied a different scale to determine the understanding level of students which generally separated into correct conception and alternative conceptions. For one-tier question, the **understanding levels (UL)** were categorized using the following criteria [31, 32, 33]:

- **Sound Understanding (SU)** for responses that include all components of the validated answers.
- **Partial Understanding (PU)** for responses that include at least one of the components of a validated answer, but not all the components.
- **Partial Understanding with Specific Alternative Conception (PUSA)** for responses that show understanding of the concept, but also made statements which demonstrated a misunderstanding.
- **Specific Alternative Conceptions (SAC)** for responses that include illogical or incorrect information.
- **No Understanding (NU)** for responses that consist of the repeating question; irrelevant or unclear response; or no response.

For the two-tier questions, the classification criteria were modified as follow [34]:

- **Sound Understanding (SU)** where both tiers are correct.
- **Partial Understanding (PU)** where one of the tiers is incorrect or insufficient.
- **Correct Choice (CC)** where only the first tier is correct and the second one is blank.
- **Specific Alternative Conception (SAC)** where the first tier is incorrect and the second one contains specific alternative conception(s)**.**
- **No Understanding (NU)** for responses that consisted of the repeating question; irrelevant or unclear response; or no response.

In this study, the test was mostly designed as two-tier questions. Therefore, the students' responses on the concept of the directionality, divergence, speed, and monochromaticity were classified using the two-tier questions criteria. The question about the intensity mainly asks students to compare the intensity of the emitted light from each light source and between two light sources with different positions. Therefore, students' responses to these questions were merely analyzed for percentages of correct answers.

III. RESULTS AND DISCUSSIONS

The responses of the students to the open-ended questions and the percentages of the students who gave responses in different levels of understanding are presented.

A. Responses to Question 1: Directionality

The first question deals with students' understanding on directionality. Students were asked to provide the position(s) that a laser beam will propagate to. Point B lays in front of the aperture while point C is far away in the axial

axis of the laser beam. In general, when lasers are turned on, the light beam will be observed only in the direction along the axial axis of the laser beam. This is called directionality. Students who understand this property would select both point B and point C. If students did not believe in the directionality of a laser beam, they would provide different answers. In the context of studying in Thailand's high schools, the relation of laser structures and the properties of laser beams are not taught so we did not expect a deep explanation of the cause of the directionality of a laser beam. The examples of students' responses to Question 1 were presented in Table II. The results showed that 55% of the students had sound understanding that is light emitted from the laser does not propagate to other points except points B and C because the laser beam does not spread out quickly.

It was found that 21% had partial understanding. Most PU students answered that the laser beam will propagate through points B and C. However, their explanations showed their main confusion. They believed that light travelling in a straight line causes the directionality of the laser beam. In order to change their beliefs, other kinds of light source such as light bulb should be illustrated. Light bulb emits light that has a trajectory in a straight path but the emitted lights do not travel to the same specific direction. Unlike laser, the emitted light travels in both a straight path and a specific direction. One PU student related the directionality to the monochromaticity. The last response in the PU category shown in Table II is interesting because this student gave an explanation concerning with the cause of the directionality. This student answered that the laser beam will propagate through only point B and provided an explanation about the compelling of the laser beam that is "laser beam trajectory is compelled to be a straight line so the laser light does not spread out". Actually, the laser components– the optical resonators which consist of two mirrors placed at the front and the back of the laser, involve in the directionality of the laser beam. During the emission process inside the laser medium, light is emitted in all direction. Lights that are radiated parallel to the axial of the laser medium will be reflected back and forth between the optical resonators causing a laser beam while other lights are loss. Therefore, the laser structure seems to influence the emitted light to travel in a specific direction as this student mention.

5% of the students were classified in the SAC category. The first response in this category in Table II was the imagination of placing objects at every interested position. According to the question, students thought that the laser light will be blocked by an object placed at point B so no light can propagate to point C. The other responses were students believed that the laser light would propagate through all positions with different methods. They explained that some parts of the light would travel forward to points B and C and other parts would be refracted to points A and D. The results showed that more than 80% of the students were familiar with the directionality of laser because they could provide the correct answer for the first tier of the question. However, most students could not give a deep explanation that associates with the laser structures and the lasing process which are the main principle of the directionality of the laser beam.

TABLE II. Percentages of the students who gave responses in different levels of understanding in Directionality.

UL	*Examples of students' responses*	*Number of students (%)*
SU	B&C: Laser beam trajectory is in a straight path without spreading. B&C: Laser has a property that it will emit light in a straight path. Laser beam will propagate to the direction that points B and C lie on.	55
PU	B&C: Laser is light and light travels in a straight path. B&C: Laser light has a single wavelength. B: Laser is a high energy light. Its trajectory is compelled to be a straight line so laser light does not spread out.	21
CC	B&C: -	10
SAC	B: Laser light travels in a straight path. It cannot pierce through an object. All points: Laser propagates through B and C because its trajectory is in a straight path. It travels though A and D because of the refraction of the beam.	5
NU	Repeating question; irrelevant or unclear response; or no response.	9

B. Responses to Question 2: Divergence

The second question of the test deals with students' understanding on the beam divergence. The question asked students to sketch the picture to represent the shape of the laser beam and provide an explanation. The effect of the laser beam divergence cannot be determined obviously in a short range distance, therefore the 10 kilometers distance was specified to avoid this problem. The students' drawings could be classified into 6 models as shown in Fig. 1. Model 1 represents a correct shape of the laser beam that diverges with a small angle while others are incorrect.

The causes of the laser beam divergence are the diffraction of light from aperture and the bending of the wave front from the curved mirror in some optical resonators. The beam divergence occurs unavoidably. These would be discussed deeply in the higher course in physics.

The distributions of the students' responses in Question 2 are displayed in Table III. The results showed that 7% of the students knew that a laser beam diverges with some angle but they could not provide the cause of the divergence. For the first-year university level, it is expected only that the students can explain the situation occurring due to the beam divergence. Therefore 4% of the students

who could explain the situation clearly were classified into sound understanding.

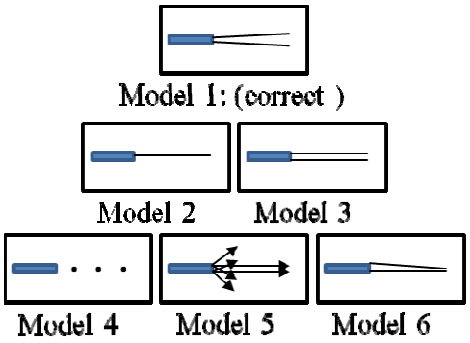

FIGURE 1. The shapes of the laser beam summarized from students' drawings.

TABLE III. Percentages of the students who gave responses in different levels of understanding in Divergence.

UL	*Examples of students' responses*	*Number of students (%)*
SU	Model1: Light travels in a straight path. When it travels in the air, it may diverge in a small angle. The intensity of light will decrease if travels for a far distance.	4
PU	Model1: Light will diverge because of the collision between the light and the molecules in the air.	1
CC	Model1: -	2
SAC	Model 2: Light travels in a straight line. If the medium does not change light does not refract or diffract. Model 2: Laser light is forced to propagate to a specific direction so the laser beam does not diverge. Model 3: Laser travels as a straight beam and the cross-section of the beam has the same shape as the aperture. Model 4: Laser spots at any position have the same size. Model 5: Light spreads out from aperture to every direction. Model 6: Some emitted lights are absorbed so the laser beam is smaller.	75
NU	Repeating question; irrelevant or unclear response; or no response.	18

It was found that 1% had partial understanding. They believed that the collision of light to the molecules of the air was the main cause of the beam divergence. Actually, the beam divergence does not occur from this reason. The phenomenon generally happens when the laser beam is propagating in the air is the light scattering from dust and this causes the visibility of the laser beam.

75% of the students were classified in the SAC category. 73% from 75% drew a straight line or a parallel beam (Model 2 and Model 3) to represent the laser beam. These students believed that a laser beam will propagate without changing its shape. The first response in the SAC category in Table III showed the connection between the beam divergence and the refraction and diffraction during the propagation of the laser beam. The second showed the connection between the beam divergence and the directionality. The third was an interesting example because these students gave an explanation referring to the optical aperture. They believed that the shape of the laser beam would be the same as the shape of an optical aperture. In addition, the difference between Model 2 and Model 3 implied that students who drew a picture as Model 2 did not pay attention to the size of a laser beam while students who drew a picture as Model 3 believed that a laser beam had a measureable beam size. The fourth response showed that students could not imagine the shape of the laser beam. They could inform their experience about seeing small spots of the laser light. In the fifth response, students believed that a laser radiates light to all directions similar to a light bulb. The last response showed the converging of a laser beam occurring due to the absorption of light. Generally, the laser systems that do not include the lens systems will radiate the diverged light beam. In other words, the paralleled and converged laser beams are produced by the collimating lens and the focusing lens, respectively.

C. Responses to Question 3: Intensity

The third question deals with students' understanding on the light intensity. This question was separated into three subquestions to investigate students' background knowledge in the intensity of both an isotropic light and laser light. The questions asked the students to compare the intensity of light emitted from a light bulb at different distances, compare the intensity between lights emitted from laser and light bulb at interesting distances, and compare the intensity of light emitted from a laser at different distances, respectively.

Question 3.1 asked students to compare the intensity of light emitted from a light bulb at different distances. Students' conception in the intensity of an isotropic light could be elicited. If students had enough background knowledge in this topic, they would provide the correct answer, that is the light intensity at A is greater than B, and B is greater than C. All students' responses are summarized in Table IV. The results showed that 78% of the students (category 1) answered correctly. Other different responses were shown in categories 2-3. These students had the alternative concepts in the intensity of an isotropic light. Furthermore, the results also showed that many students (19%) still had no ideas about the comparison of the intensity of an isotropic light.

TABLE IV. Percentages of students who gave responses to Question 3.1 in each category.

Category	*Answer*	*Number of students (%)*
1	A > B > C	78
2	C > B > A	2
3	Etc. (B > A > C, A is the greatest,…)	1
No understanding	-	19

Question 3.2 asked students to compare the intensity of light emitted from a laser and light emitted from a light bulb at interesting positions. The answer of this question generally appears in the real life. The laser light intensity is still high while the light radiated from a flashlight attenuates rapidly when shined to the back of the room. The correct answer is that intensity of light emitted from a laser is greater than that from a light bulb at both point B and point C. Students' responses to Question 3.2 are presented in Table V. The results showed that 76% of the students (category 1) answered correctly. This implied that most students had an ability to compare the intensity between two light sources and they also knew that the trends of the intensity changing of both light sources were different. 6% of the students (category 2), who answered that the intensity of the laser beam is equal to the light bulb at all points, did not have any idea about the laser intensity. 2% of the students (category 3) believed that the intensity of the laser beam decreases more quickly than that of the light bulb. The other 16% had no understanding.

TABLE V. Percentages of students who gave responses to Question 3.2 in each category.

Category	*Answer*	*Number of students (%)*
1	Intensity of laser is greater.	76
2	Equal intensity at all points.	6
3	Intensity of laser is smaller.	2
No Understanding	-	16

Question 3.3 asked students to compare the intensity of the laser beam along the axial distance. This question elicited students' beliefs in the relation between the intensity of laser and the distance directly. The correct answer is that the light intensity at A is greater than at B, and B is greater than at C. To explain the trend of intensity decreasing, students required the background knowledge in laser mode and Gaussian beam that are difficult to the first-year level.

TABLE VI. Percentages of students who gave responses to Question 3.3 in each category.

Category	*Answer*	*Number of students (%)*
1	Less than intensity at point A.	16
2	Intensity at points A, B, and C are equal.	73
3	Greater than intensity at point A.	2
No Understanding	-	9

Students' responses to Question 3.3 are presented in Table VI. The results showed that only 16% of the students (category 1) answered correctly. Most of the students (category 2) believed that the intensity of the laser beam at points A, B, and C were equal. Students' beliefs might come from their familiarity with seeing a bright spot of laser light at a far distance. This causes from the saturation of the eyes that affect the observer's ability to determination the intensity of light. This might mislead students to conclude that the laser beam intensity does not change along the propagating distance. A few students (category 3) thought that the intensity of the laser beam at points B and C are greater than that at point A while 9% had no understanding.

The above results of questions 3.1, 3.2, and 3.3 implied that most students had enough background knowledge about the intensity of an isotropic light but had alternative concepts about the intensity of laser. They had strong belief that the intensity of laser light is constant along the distance of propagation.

D. Responses to Question 4: Speed of laser light

The fourth question of the test deals with the students' understanding on the speed of laser light. This question involves the comparison between the speed of light emitted from a laser and a light bulb. Both lights are electromagnetic waves that propagate in the air so they travel at the same speed *c*. In other optical media, the speed of an electromagnetic wave depends on their wavelength.

The distributions of students' responses are shown in Table VII. The results showed that 63% of the students (SU, PU, and CC) knew that both lights have the same speed. Only 54% (SU) could present proper reasons. These students had enough background knowledge about the effecting factors to the speed of an electromagnetic wave.

It was found that 2% had partial understanding. There are two types of PU students' confusions. The first response in the PU category in Table VII showed the confusion in determination of the speed of light from the frequency. The second response showed the confusion in the identification of the frequency of white light and laser light. These students believed that light emitted from a laser has higher frequency than light emitted from a light bulb.

For the SAC category, most students believed that light emitted from a laser propagates with higher speed than general light due to some factors such as the intensity, frequency and directionality (SAC; responses 1, 2, 3 and 4). Some students thought that laser radiates the accelerated light (SAC; response 5). Moreover, some students (SAC; responses 6 and 7) believed that laser light propagates slower than general light. There are two types of confusions shown here. Firstly, laser light propagates with a speed equal to that of the activated electrons. The other related the intensity or wavelength to determine the speed of light. These students believed that light with higher intensity has a shorter wavelength which is directly proportional to the speed due to the equation $v=f\lambda$.

E. Responses to Question 5: Monochromaticity

The last question of the test deals with the students' understanding on monochromaticity. Light emitted from a laser is usually called "monochromatic light". It is also often said that "laser light is a single frequency light". Another popular monochromatic light source is the Sodium Vapor lamp. When the monochromatic lights propagate through different optical media, the dispersion cannot be clearly observed. Light emitted from the LED (Light Emitting Diode) also refracts without clearly observation of dispersion. Therefore, the observed light in this question could be the monochromatic light which could be either green light emitted from laser or green light emitted from LED.

The correct responses were divided into two types as shown in Table VIII. Firstly, the light source is laser (SU; responses 1, 2, 3 and 4). The refracted laser light does not disperse to be multiple colors. Laser light refracts and produces a spot of green light at the bottom of the tank. Most of the SU students provided the answer in this way. Many students were familiar with this situation because the refractions of the laser light are generally shown in textbooks and on the internet. Another type of the answer was also provided from a few students - the light source in the question is possibly a laser or a special light source such as LED. Both of them emit light that are refracted without a clearly observed dispersion. Both laser light and general light which have the same wavelength will refract with the same angle of refraction (SU; response 5). This type of the response showed a good understanding in refraction of light.

It was found that 11% of the students had partial understanding which contains two types of confusions. First, they emphasized in the refraction of light instead of dispersion (PU; response 1). Their reason is the laser light can refract so the observed light is radiated from a laser. Actually, lights always refract when propagate through different optical media but the dispersion does not always occur, it happens for only light with a large spectral width. The second response showed that the confusion came from the experiences about the observation of a laser light propagating in water (PU; response 2).

TABLE VII. Percentages of the students who gave responses in different levels of understanding in Speed.

UL	*Examples of students' responses*	*Number of students (%)*
SU	Equal: Both are the electromagnetic waves. They travel in the same medium. Equal: Both are electromagnetic waves or light. They travel with the speed of light. Equal: Speed of light does not depend on the type of light source.	54
PU	Equal: Both are visible light with the same frequency. Equal: According to $v=f\lambda$, Laser light has higher frequency and shorter wavelength while general light has lower frequency and longer wavelength. The multiply of frequency and wavelength are the same.	2
CC	Equal: -	7
SAC	Less: Light from light bulb has less intensity than laser. Less: When the distance increases the light emitted from the light bulb will propagate slower until it evanesces, but the laser light still retains the same speed. Less: From $v=f\lambda$, light emitted from the laser has higher frequency than the normal light so the speed of the laser light is greater than the speed of the normal light. Less: Laser light propagates to a specific direction. Less: Light emitted from the laser is accelerated so it has higher speed than the normal light. Greater: Light emitted from the light bulb propagates with speed of light but laser light propagates at a speed equal to the activated electrons. Greater: The laser light has higher intensity thus it has a shorter wavelength which causes a slower speed.	18
NU	Repeating question; irrelevant or unclear response; or no response.	19

Considering the SAC responses, the main alternative concept was the belief that laser beam trajectory is unchanged when it propagates through different optical media (SAC; response 1). The second was the belief that laser light must only be red color (SAC; response 2). Many students were familiar with red color laser because they usually appeared in daily life such as a laser pointer used in a presentation, laser light shown in some toys, etc. In the future, this type of alternative conception might be disappeared when other colors of laser light, such as green and blue, are widely used in daily life.

TABLE VIII. Percentages of the students who gave responses in different levels of understanding in Monochromaticity.

UL	*Examples of students' responses*	*Number of students (%)*
SU	Yes: Laser light is monochromatic. Yes: When the normal light refract, it spreads out into different colors as a rainbow but the refracted light in the question has only one color so it must be emitted from a laser. Yes: All observed light has the same wavelength. That is one property of laser light. Yes: All observed light is in the same region in the spectrum band. That is one property of laser light. Can be both laser or general light: Light can refract, it does not depend on the light source. If green light is radiated to the water, the observer can see the green spot at the bottom of the water tank.	26
PU	Yes: Laser light can refract. Yes: Laser light propagates in water better than general light.	11
CC	Yes: -	21
SAC	No: Laser light does not change the direction when travelling to a different medium. No: Laser light has only red color.	7
NU	Repeating question; irrelevant or unclear response; or no response.	35

IV. CONCLUSIONS

From the literature reviews, the students' conceptions in the properties of light as an electromagnetic waves had been investigated already. These researches showed many kinds of students' alternative conceptions [35, 36, 37, 38, 39, 40, 41]. Most of these surveys provided the questions or situations which were related to the general light. They were not specifically asked about laser light. Although, the investigations of the students' conceptions in the general properties of a laser light as a kind of the electromagnetic waves are important, the surveys of the students' conceptions in the unique properties of a laser light that different from general light are also greatly interesting. It is important to know students' background knowledge in the properties of laser in order to provide advantages to them in keeping up with the fast pace of technology change nowadays.

This research is a survey of students' background knowledge in laser properties. It focuses on eliciting students' background knowledge in five basic essential and observable properties of the laser beam, namely the directionality, divergence, intensity, speed, and monochromaticity. Although, most students had experiences with laser in their life, they could not provide satisfactory answers to the open-ended question. The results showed the students' responses in the different levels of understanding. It revealed that most of the students (greater than a half) had deficient background knowledge in these topics. Students had the best background knowledge in the Directionality while the Divergence was the topic that students had the weakest background. Student understanding levels and their alternative conceptions in each topic are summarized as follows:

- **The Directionality:** 55% of the students had sound understanding while 26% were classified in the PU and SAC categories. A half of students seem to have correct concept in this topic while one-fourth of them had some confusions. Students' responses showed that many of them had an idea about the directionality of light (light travels in a straight line). This finding is the same as found previously in other researches [36, 42]. Some students used this idea to explain the directionality of the laser beam (lights emitted from laser travel to a specific direction).
- **The Beam Divergence:** Only 4% of the students had sound understanding while most students (75%) were classified in the SAC category. This means that three-forth of the students had some confusions in beam divergence. The main alternative conception is the belief about laser propagating without changing its shape which might occur from the unclear- observable divergence of a laser beam.
- **The Intensity:** Greater than 70% of the students could compare the intensities of an isotropic light at different distances. They also had enough background knowledge to compare the intensities of a laser light and an isotropic light. However, most students (greater than 70%) still had the main alternative conception about the intensity of the laser beam still being constant along the travelling distance.
- **The Speed of Laser Light:** 54% of the students had sound understanding. 20% were classified in the PU and SAC categories while 19% had no understanding. The results revealed that about a half of students were confused in determining the speed of laser light. The main alternative conception is the belief that the speed of laser light is higher than general light.
- **The Monochromaicity:** 26% of the students had sound understanding. 18% were classified in the PU and SAC categories while 35% had no understanding. The results indicated that many students were confused in determining the kind of light (monochromatic light or general light) from the observable refraction. The detected alternative conceptions are the unchanging of laser beam trajectory when it propagates through different optical media and the laser light must only be red color.

Finally, the conclusions of the work avail to the teachers and general educators in order to develop the instructional instruments in laser topic. Instructors can use these results to create the multiple-choice test for evaluating students' understanding in the properties of the laser beam. The

detected alternative concepts can be used to set up an effective teaching process and tools for their classes.

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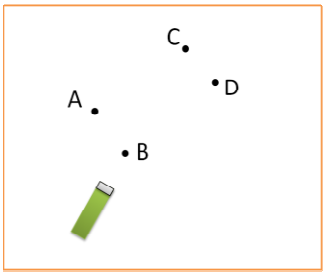
APPENDIX

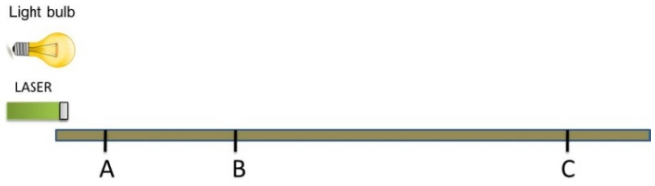
The open-ended test on Laser Properties

Question 1. The laser is placed as shown in the picture and then its switch is turned on. Which point(s) can the laser light propagate through? Explain your answer.



Question 2. The laser light is emitted from the top of mountain A to the top of mountain B which is 10 kilometers apart. Sketch the picture to show the shape of the laser beam propagating to mountain B and explain your answer.

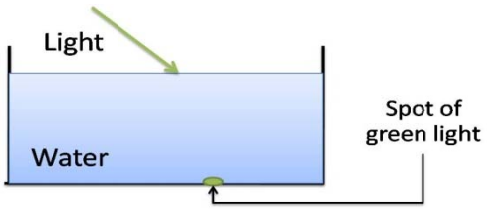
Question 3. The laser and the light bulb are placed as shown in the picture.



3.1 Compare the intensity of the light emitted from the light bulb at points A, B and C.
3.2 When the laser and the light bulb are turned on, the intensity of the emitted light from both light sources at point A are equal. Compare the intensity of the laser beam and the intensity of the light emitted from the light bulb at points B and C, respectively.
3.3 The laser is turned on, Compare the intensity of the laser beam at points B and C to that at point A.

Question 4. Compare the speed of light emitted from a light bulb and the speed of light emitted from a laser when they both propagate in air. Explain your answer.

Question 5. The light from an unknown light source propagates from air through water in a tank as shown in the picture. The observer can see only the spot of green light at the bottom of the tank.



Is the unknown light source a laser? Explain your answer.