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Project-Based Learning on Laboratory Experiment about Refraction and Total Internal Reflection of Different Types of Materials

Ahmad Swandi [1*)], Sri Rahmadhanningsih [2], Bunga Dara Amin [3], Nurhayati [4], Sparisoma Viridi [5], Chi-Hung Chang [6]
Universitas Bosowa, Indonesia[1], Institut Teknologi Bandung, Indonesia[2,5], Universitas Negeri Makassar, Indonesia[3], STKIP Singkawang, Indonesia[4], National University of Kaohsiung, Taiwan[6]
[*)]Corresponding E-mail: ahmad.swandi@universitasbosowa.ac.id

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ABSTRACT
The use of Project-Based Learning (PjBL) in Physics Learning has been widely used, but only as a learning model that is used to determine its effects on students. Whereas PjBL can also be used as a model to produce new information and experimental tools with the right method. This research is a laboratory experimental study that aims to produce an experimental device to determine the refractive index of various materials using refractive and perfect reflection methods. To complete this research, the team followed the steps of PjBL which consisted of 7 stages, namely Challenging Problems or Questions, Sustained Inquiry, Authenticity, Student Voice and Choice, Reflection, Critique and Revision, and Public Product. By following the PJBL stages, the team succeeded in producing an experimental device with good results. The results show that the experimental device produced works well and is able to determine the refractive index of the material with a fairly accurate value where the error value is below 1%. From this process also, the team acquired more skills, namely critical thinking, problem-solving, communication and collaboration.

INTRODUCTION

Currently, most of physics learning only focuses on learning theory in the classroom, although theory learning is important to make students have a deeper understanding of concepts, sometimes this method often results in students feeling bored with monotonous learning and not exploring the ideas they have [1]. Their skills also do not develop so there needs to be a combination of learning methods to do by the lecturer. Nowadays, several universities also implement laboratory observations (practicum) for certain subjects [1]. In practicum activities, the lecturers and instructors have determined the topic of observation along with the modules that are used as guides during the practicum. Students are also assisted by instructors so that the practicum process runs well. Whereas with the understanding of physics obtained by students, they can explore their ideas to find problems from a certain topic, compile their experimental plans, carry out experiments in the laboratory, analyze and report their findings [2] [3]. However, lecturers and universities have very little to do with this [4].

Various learning models can be used by lecturers in order to students produce new products or new concept or theory in physics. So that learning does not only focus on the transfer of knowledge in the classroom, but students' scientific abilities must be explored. This is very important to support learning that is interesting, meaningful and not monotonous. One learning model that can be applied is PjBL. Based on our observations while studying at the Bandung Institute of Technology postgraduate program, Learning models like this have been implemented by majority courses in the physics department.

By applying the PjBL model, it helps students to explore their knowledge and skills through providing workloads for a certain period by the lecturer. Students are also expected to be able to solve complex problems, questions, or challenges, investigate and respond authentically and interestingly [5]. Several studies have shown that the use of PjBL in learning has a good impact on students concerning understanding concepts and developing skills such as collaboration, critical thinking, and problem-solving [6]. Research conducted by Trianto shows that learning with PjBL can increase motivation and learning outcomes by using problems related to certain subjects [7]. In addition, Gunawan et al's research show that there is an effect of the application of PjBL on student creativity in learning physics [8], but this study only uses virtual media or virtual laboratories as a learning tool. In other words exploration, assessment, interpretation, synthesis and information are carried out with the help of data from virtual laboratories instead of real laboratories. In fact, PjBL must encourage students to look for problems, carry out investigations with correct scientific steps, apply knowledge and experience to produce new products or concepts. In learning Physics with PjBL, students are expected to be able to design their experimental tools to test a concept or product and find scientific conclusions to get new, reliable products.

However, it is rather difficult for lecturers to implement PjBL in learning because most students still need support and guidance so that the project can run [9]. Therefore it takes great support from lecturers to plan and implement PPAs effectively, lecturers need to provide initial directions and ideas while students need help to organize and direct initial investigations, manage time to complete assignments, and integrate technology into projects in a meaningful way. [10]. The PjBL method can be applied to various subjects, especially science and engineering, one of which is in learning physics such as research conducted by Gunawan which uses virtual media assisted by PjBL in physics learning [8]. Likewise, what was done by Chandra et al, who succeeded in producing a thermometer using certain materials through project-based learning. In general, students learn physics by attending lectures using various methods in class or reading reference books about related concepts. There is also research conducted by Swandi et al which succeeded in making simulations related to electric fields by continuous charges through PjBL [11].

but with PPA students feel a big responsibility to explore ideas, carry out investigations both independently and with the team, improve cooperation and communication skills and produce deep understanding because they are obtained in a meaningful and fun way. Some examples of the benefits of using PPAs are the production of new products or concepts that are published in several scientific articles by ITB students, besides after the application of the PjBL method to a group of University of Delaware physics students it appears that all students have a better understanding of the material. their knowledge and problem-solving skills are also developing [11].

The PjBL model with the laboratory experimental method is very good for application in learning physics in universities. With PjBL, various products can be developed and tested to have more useful values in society, one of which is in schools. Most of the physics concepts have been investigated with certain experimental equipment but with different methods and unfavorable results. One of them is related to the determination of the refractive index of various materials which can be done through the concept of refraction and perfect reflection. In this article, the researcher reports the results of developing the experimental set and the results of the trials to determine the refractive index value of materials by two methods.

METHOD

This research is an experimental laboratory research. The research was carried out on a laboratory scale by making experimental devices related to refraction and perfect reflection of various types of materials carried out by the Project-Based Learning method through 7 steps namely Challenging Problems or Questions, Sustained Inquiry, Authenticity, Student Voice and Choice, Reflection, Critique and Revision, and Public Product [8] [11]. The object of this research is a set of experiments of perfect refraction and reflection with various materials, namely glass, water, and oil. The purpose of this study were (1) to determine the refractive index value of glass, water, and oil using two methods, namely refraction and total internal reflection, (2) to obtain the experimental product tested related to the phenomenon of light waves. This product can be used by the community, especially in schools as a teaching aid for physics learning.

Primary data were collected through experiments and observations in the laboratory using pre-designed products. Primary data are incidence angle and bias angle. Meanwhile, secondary data is obtained through literature references. The primary data obtained were then analyzed using the matlab application by looking for the gradient plot between the sine of the incidence angle and the sine of the bias angle. The gradient is then analyzed to determine the value of the refractive index and then compared with the refractive index of secondary data obtained from the reference.

RESULTS AND DISCUSSIONS

Challenging Problem or Question

Currently, the determination of the refractive index of certain materials has been carried out, such as the research conducted by Firdaus et al which examined the quality of cooking oil with the concepts of viscosity and refractive index [12]. However, the method used is refraction with a prism. Even though several methods can be used both by refraction and by the method of total internal reflection. Both methods also require equipment that we can get easily. Therefore, during Physics II learning related to electromagnetic waves, we were challenged by lecturers and tutors to complete a project to determine the refractive index value of various materials using these two methods. The main question our team has to solve is how to make a perfect refraction and reflection experimental device? What equipment is needed? Which of the two methods is used which gets a value that is closer to the reference value? We found this particular question very precise, interesting and very challenging for our team.

Sustained Inquiry

Various questions were raised, required in-depth investigation to answer these questions. The first important point to investigate is what is refraction and total internal reflection? Refraction is a physical phenomenon where a wave will experience bending when it passes through two different mediums. In this phenomenon the angle of refraction varies according to the angle of incidence of light at the boundary between the two different mediums. Meanwhile, total internal reflection has a definition almost the same as refraction, but in this phenomenon, if the angle of incidence is enlarged, the angle of bias will be large and one day the angle of bias is equal to 90^0. In other words, the rays are refracted parallel to the boundary plane between the mediums.

The next question is how to get research data. What parameters need to be measured in order for the refractive index of glass, water and oil to be determined? To determine the refractive index of the three materials, light is directed from the air towards the surface of each material that is placed on the paper. The light beam is then marked with dots and then drawn. From this image we can determine the value of the angle of incidence and the angle of bias as shown in Figure 1 (a) and (b).

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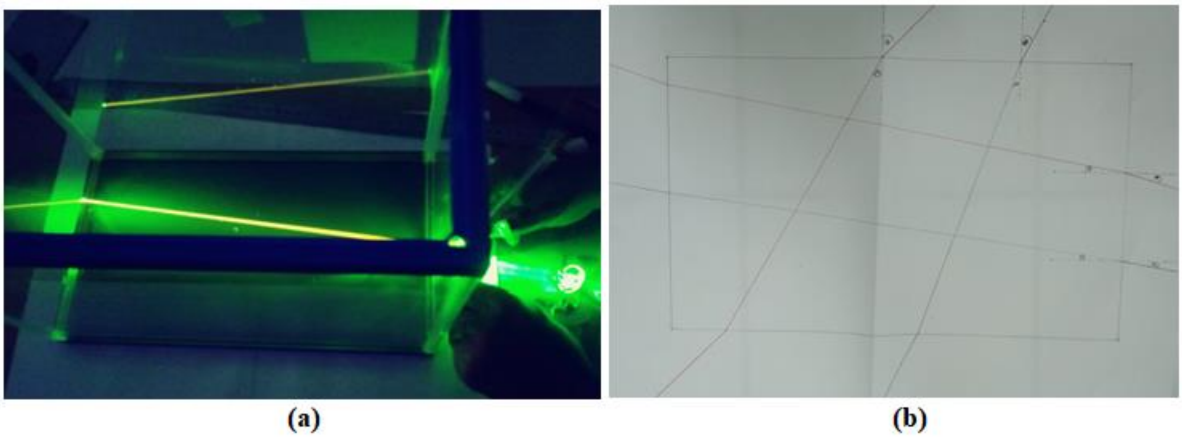

Fig 1. *(a) Refraction to water, (b) The pattern of refraction in water.*

In Figure (a) it can be seen that water is put into a container that is large enough, the thickness of the container is much smaller than the width and length of the water in the container so that refraction in the layer of the container can be ignored. The laser beam is then directed to the surface of the container that has been placed on the paper. The experiment was carried out in a dark room so that the light beam could be seen easily. Furthermore, the light beam is marked (dots) on the paper then the marks (dots) are connected to describe the light beam as in Figure 1 (b). From this figure, the angle of incidence and the angle of bias can be determined.

Authenticity

The next question is how to test the originality of the experimental device? Did the experimental device produce authentic values? If an incident ray does not travel straight towards the surface, the reflection changes the direction the light travels. If a refracted beam lies within the incident plane and has a refractive angle θ_2 which corresponds to the incident angle θ_1 as follows [12]

$$n_1 \sin \theta_2 = n_2 \sin \theta_1 \quad (1)$$

n_1 and n_2 are a dimensionless constant called the refractive index, this is related to the material (medium) that is included in the refraction. We derive this equation to Snell's law. Where the refractive index of a medium is equal to *c/v*, where *v* is the speed of light in the medium and *c* is the speed in a vacuum (vacuum). We can arrange the equation as follows.

$$\sin \theta_2 = \frac{n_1}{n_2} \sin \theta_1 \quad (2)$$

to compare the bias angle θ_2 with the incidence angle θ_1. Then we can see that the relative value of θ2 depends on the relative value of n_1 and n_2 .

In the refraction process, glass, a container filled with water and a container filled with oil are placed on the paper. The medium shape pattern is then depicted on the paper. The light is then directed from the air with a certain angle of incidence towards the medium where it is visible to the eye that the light beam is deflected close to the normal line, then the light then comes out and is deflected into the air into the normal line. In the air, the trail of rays can be seen by placing a protractor. So that we get 4 light beam points.

As the angle of incidence increases, the angle of refraction increases: for light e it is 90^o which means that the rays are refracted directly towards the surface. The angle of incidence makes this situation what it is called the critical angle θc. For incident angles greater than θc, such as for rays f and g, no rays are refracted and all light is reflected; this effect is called total internal reflection. To find θ_c, we use Equation 2; We freely associate subscript 1 with glass and subscript 2 with air, and then we change θ_c for θ_1 and 90° for θ_2. Then:

$$\theta_c = \sin^{-1}\frac{n_2}{n_1} \tag{3}$$

since the sine of an angle does not exceed the compound, n_2 cannot exceed n_{21} in this equation. This limitation tells us that total internal reflection cannot occur when the incident ray is inside a medium with a smaller refractive index. In the perfect reflection process, the shape of the glass we use for refraction is changed from a block to a semicircle where both have the same refractive index because the type of glass is the same. It is intended that the rays coming from the air to the glass are always perpendicular so that there is no refraction. To make it easier, we put the glass on top of an arc where the arc can rotate. The light is then directed to the part that is curved towards the midpoint of the arc on the horizontal side, the light is then reflected and refracted. By rotating the arc, we direct the refracted light so that it is parallel to the horizontal part of the glass.

The beam of light in the liquid can be observed visually easily, then the height of the light in the liquid and its length can be determined by means of two rulers attached to the part of the container. Using the equation $\tan\theta$ the critical angle θ_c can be determined Determination of the refractive index of various types of medium is carried out by two methods, namely by determining the angle of incidence and refractive angle and the second method is determining the critical angle for perfect reflection. The observational data are as shown in Table 1.

Table 1. The results of the measurement of the incidence and refractive angle of the rays in various types of medium

No.	Type of Materials	Part	Coming Angle θ_1^0	Refraction Angel θ_2^0
1.	Glass	Length	$\lvert 27.0 \pm 0.5\rvert$	$\lvert 15.0 \pm 0.5\rvert$
			$\lvert 30.0 \pm 0.5\rvert$	$\lvert 19.0 \pm 0.5\rvert$
		Width	$\lvert 11.0 \pm 0.5\rvert$	$\lvert 7.0 \pm 0.5\rvert$
			$\lvert 20.0 \pm 0.5\rvert$	$\lvert 13.0 \pm 0.5\rvert$
2.	Water	Length	$\lvert 41.0 \pm 0.5\rvert$	$\lvert 29.0 \pm 0.5\rvert$
			$\lvert 27.0 \pm 0.5\rvert$	$\lvert 20.0 \pm 0.5\rvert$
		Width	$\lvert 18.0 \pm 0.5\rvert$	$\lvert 13.0 \pm 0.5\rvert$
			$\lvert 14.0 \pm 0.5\rvert$	$\lvert 10.0 \pm 0.5\rvert$
3.	Oil	Length	$\lvert 28.0 \pm 0.5\rvert$	$\lvert 20.0 \pm 0.5\rvert$
			$\lvert 45.0 \pm 0.5\rvert$	$\lvert 30.0 \pm 0.5\rvert$
		Width	$\lvert 15.0 \pm 0.5\rvert$	$\lvert 10.0 \pm 0.5\rvert$
			$\lvert 10.0 \pm 0.5\rvert$	$\lvert 7.0 \pm 0.5\rvert$

Table 2. Critical Angles in Various Types of Medium

No.	Type of Materials	Deviation, y (cm)	Distance from Center, x (cm)	Critical Angel, θ_c^0
1.	Glass	-	-	41.0
		-	-	40.0
2.	Water	$\lvert 7.20 \pm 0.05\rvert$	$\lvert 7.50 \pm 0.05\rvert$	46.12
		$\lvert 7.40 \pm 0.05\rvert$	$\lvert 7.70 \pm 0.05\rvert$	46.12
3.	Oil	$\lvert 4.00 \pm 0.05\rvert$	$\lvert 4.10 \pm 0.05\rvert$	45.71
		$\lvert 4.00 \pm 0.05\rvert$	$\lvert 4.00 \pm 0.05\rvert$	45.0

The measurement of the coming angle and the refraction angle was carried out 4 times in different directions, this aims to get more data so that it is more convincing when analyzed using graphs. From table 1 it can be seen that there is a decrease in the angle of bias when compared to the coming angle. This is in accordance with the theory of refraction which states that light traveling from a tenuous medium to a dense medium will be refracted close to the normal line. In other words, the refraction angle decreases. Furthermore, for activity 2, data collection related to Total Internal Reflection was carried out and obtained data as in table 2.

On glass, we can easily get the critical angle because the angle gauge can easily be placed under the glass. It is different from water and oil which are placed in a large enough container, so to obtain critical angle data, different methods must be used, namely by measuring the distance of deviation (vertical) and the horizontal distance to the total internal reflection point. The critical angle data are then obtained using trigonometric equations.To determine the refractive index of refraction we plot a graph of the relationship between sin θ_1 and sin θ_2. From the graph then we determine the regression value. Here is a relationship between sin θ_1 and sin θ_2 for the "width" part, as shown in Figure 2.

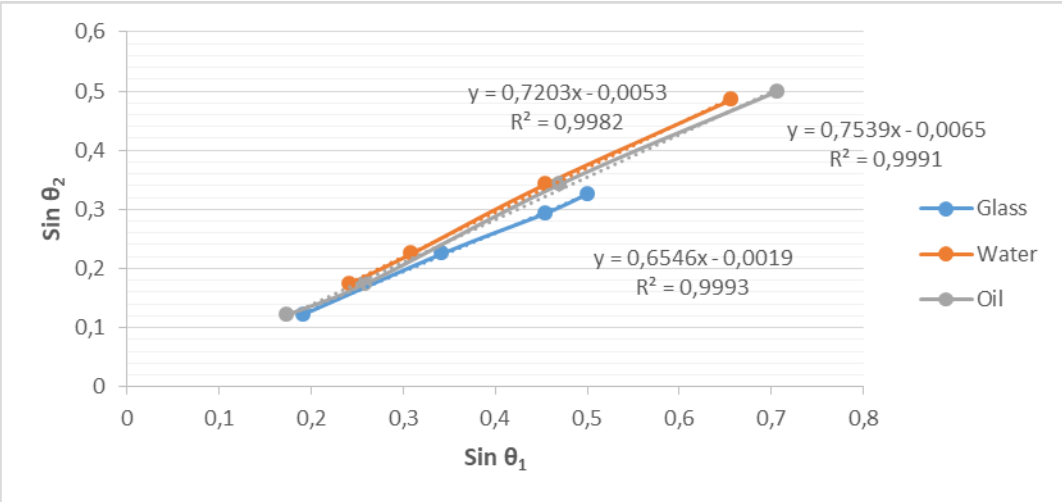

Fig 2. *The graph of the relationship between the incidence angle and the bias angle. from the gradient can be determined the refractive index of each material*

From the graph above, we can determine the value of the refractive index. Using the Snellius equation, the slope of the graph (gradient) is 1/n. In other words, the refractive index of the medium is 1/m where m is the slope of the graph. So that the refractive index values of glass, water and oil are obtained, namely 1.5276; 1.3264, and 1.3883.

When compared with the reference, the refractive index of glass is 1.5168 [13], the refractive index of water is 1.33 [12] and the refractive index of cooking oil is 1.47 for a temperature of 50 ^{0}C [14]. So that the error value of the refractive index of glass, water, and oil is 0.71%, 0.27% and 8.2%, respectively. When viewed, the error value for glass and water is below 1% which indicates that the refractive index value obtained is close enough to the refractive index by reference. While for oil has a large enough error value, namely 8.2%. The error value in the refractive index of oil is caused by several factors, namely the refractive index value taken by reference applies to cooking oil with a temperature of 50 ^{0}C, while at the time of measurement, the oil temperature is 25 ^{0}C. In addition, in the market we can find various types of cooking oil. While the reference refractive index value does not mention the type /brand of the cooking oil.

From the observations, we can determine the value of the distance between the ends of the medium from the vertical and horizontal rays. From this variable we can determine the average critical angle. The average critical angle values for glass, water and oil are respectively as follows 40.50; 46,120 and 45,350. From this critical point of view we get the refractive index value of 1.5398; 1.3873 and 1.4056. The percentage of errors for the refractive index of glass is 1.51%; water 4.3% and oil 4.38%. In general, the error value obtained from perfect reflection is greater than the error from refraction. This is due to several factors, namely reading the vertical and horizontal end of the medium-scale value is very difficult to do because the light source and the medium cannot be perfectly still. In addition, error in reading the scale is difficult to avoid due to the position of the beam, scale and observer is not correct. The material temperature factor also affects, as a comparison of the refractive index value of water by reference is 20 ^{0}C and 50 ^{0}C oil, while the temperature of both at the time of observation is 25 ^{0}C.

Apart from that, there are several interesting things in this observation, among others: (1) the diameter of the laser beam in water is almost the same in every position, whereas in different oil, the diameter gets bigger as the position of the initial light gets bigger; (2) a straight beam of light (horizontal with the surface of the medium facing the air) is not a point but diffused light even though there is the brightest part.

Student Voice & Choice

While carrying out this project, our group as project implementers made decisions based on our knowledge and information from the literature, decisions were based on discussions with team members, students and lecturers. For example, (i) choosing to use a container that is large enough with the thickness of the container much smaller than the length and width of the container, this is aimed at ignoring the refraction process that occurs in the container; (ii) to obtain various measurements, we decided to use two methods, namely refraction and total internal reflection, that the refractive index value obtained can be compared with the value of the reference; (iii) to obtain more reliable refractive index data, it is necessary to obtain a gradient plot value between the incidence angle and the refractive angle sine value. The ideas and decisions developed by our team above make project participants feel more involved in the process. Each idea is conveyed first to the lecturer during the learning process.

Reflection

During the project implementation period by applying PjBL Standard Gold developed by the Buck Institute of Technology, the team found the learning experience of many good things, (i) PjBL made learning fun, memorable and interesting and there was deep interaction in the form of questions and answers between lecturers and team as well as between teams with other teams. The concepts, methods, products we get are thoroughly tested. This is in accordance with the opinion of Canra et al, who stated that with PjBL, lecturers and tutors challenged the team to carry out physical activities in the laboratory so that the learning process felt more meaningful than just theoretical learning [8]. (ii) The gold standard PjBL that we follow can improve problem-solving skills. We learn how to collect data to find the most effective and efficient solution to a problem. This is in accordance with Thomas's opinion which states that project-based learning is a learning model that is able to teach students about the process of solving various problems from initial information. Initial information was obtained from students followed by giving high-level problems so as to train students to find and analyze to solve these problems. Harper cites that the focus of project-model learning is an in-depth investigative process that involves long and rigorous question and answer between the team and the lecturer, using resources and developing answers; and focus on open-ended questions to understand and attract students' attention in capturing the project [15]. Muskania & Wilujeng said that PjBL begins with giving problems that lead to the final product that will be produced by students [16]. (iii) The project team is also trained to improve critical thinking skills. The initial problems and questions were obtained and consulted by experts, giving rise to many new and quite complex questions. The team was asked to be able to think critically about the question. This is in line with Hendrik & Ihtiari's opinion which explains that the project-based learning process in an application supports the development and improvement of students' critical thinking skills [17]. Sumarni further stated that through projects, students do not need to memorize any theory or equation (formula), but rather analyze and think critically about the information from the formula collaboratively to solve problems [18]. The project approach concentrates more on process than on content.

In addition, collaborating with teams and other students during project implementation is a very important activity. Collaboration is one of the characteristics of working on projects with the aim of helping students exchange ideas and communicate. Astawa, Artini, & Nitiasih explained that the project learning stage trains students to be active and think creatively and to be involved in collaboration [19]. Project-based learning allows students to gain a deeper understanding of the material by collaborating and using their ideas (active construction). Social interaction allows students to work with others to build shared knowledge. Williams explained that project-based learning provides opportunities for students to be actively involved during learning and opportunities to learn new soft skills such as collaboration, communication, and negotiation [20]. Rashid, & Bakar stated that communication and teamwork skills are skills that can be trained through project activities [21]. Harper continued that PjBL is one of the important elements that can train 21st-century skills, one of which is communication skills [15]. The final stage of project-based learning is evaluating the project activities that have been implemented. Based on experience, the team feels happy and motivated in making projects they have completed. Students acquire more new knowledge and skills during project completion while feeling motivated to complete the project. This was stated by Sumarni that one of the advantages of using PjBL in learning can increase student motivation [18].

Apart from the points above, the PjBL method has also succeeded in training team members in several soft skills, including the ability to decide and consider something to evaluate work progress and develop critical thinking. In addition, PjBL also provides valuable experience on how to be guided by experts to find problems and solve them with scientific steps. With the various reflections mentioned above, our team hopes that this ability can be useful for the individual development of each project participant, as well as for further developing the products we design in the future.

Critique and Revision
During project work, our team received a lot of criticism and suggestions from lecturers, experts and tutors. These criticisms and suggestions are for the benefit of the project as well as future development. Some of the criticisms conveyed by lecturers and tutors are: (i) to be more accurate, increase the number of measurement data for one material, this is done so that gradients can be obtained; (ii) data collection should not only be from one side of the material so that it can be used as a comparison when getting bad data; (iii) Apart from that, the lecturer also suggested that lasers with different colors such as red should be used. It is important to know whether there are differences in the results obtained.

Public Product
The products produced in Project-Based Learning are called "experimental devices for refraction and the perfect reflection on various materials". This device is successfully assembled with a fairly small error size. The next process that must be followed in implementing PBL Gold Standard is the presentation of products that have been produced in public. Our team prepares slide presentations and ensures the readiness of experimental devices developed for demonstrations in front of lecturers, experts, tutors and fellow students. The final product of this project can be used by the community, especially in laboratory-based physics learning (experiment). The products obtained in this project can be retried at both schools and colleges.

CONCLUSION AND SUGGESTION

The trial kit of refraction and total internal reflection for some materials have successfully been produced by followed the seven steps of the Gold Standard PjBL. The refractive index can be determined by experimenting with this method and the value obtained determines the true (reference) value. Refractive index can be used in 2 ways, namely refraction and total internal reflection. The refractive index of glass, water and oil from the refraction method are 1.5276, 1.3264, and 1.3883. The error percentage for glass and water below 1%, while for oil above 8%. For the total internal reflection method, the refractive index value is obtained, namely 1.5398, 1.3873, and 1.4056 with an error percentage of below 4%. By looking at the relatively small percentage of errors, the equipment prepared used in this experiment can be used as teaching aids for physics learning. In addition, through the use of the PjBL model in project completion, we have succeeded in improving critical thinking, communication, collaboration, and problem-solving skills.

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