Analysis of understanding in the speed of an electromagnetic wave and in the principle of refraction: a case study of KMUTT (Ratchaburi) engineering freshmen

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Abstract. Learning achievement in fundamental electromagnetism performed by 110 engineering freshmen, enrolled in 2017 at King Mongkut's University of Technology Thonburi (Ratchaburi), is presented. Activities for the class had not only been conducted by traditional lecture, but also with an integrated project assignment. Two key concepts in physics, the speed of an electromagnetic (EM) wave and the principle of refraction, delivered to students by two different teaching and learning methods are selected for comparison. Preliminary results are analysed from students' scores in the final examination. Some of students' misconceptions are found in both selected topics. From the comparison, the teaching and learning methods through the project activity, together with the lecture, seem to yield a great number of well-understood students than those through the lecture alone. Further investigation is also discussed based on the rank of students' scores. The findings in this paper stress an importance of well-designed projects that complement the traditional lectures in classroom.

1. Introduction

Electromagnetism is one of the most important topics for first-year university physics. Students need to have correct concepts as a foundation to attain advance knowledge in a higher level of study. Therefore, many bodies of research have been done extensively to identify students' misunderstanding in order to improve learning and teaching in this topic [1-2]. It has been noticed form teaching experiences of the authors that many first-year students at King Mongkut's University of Technology Thonburi (Ratchaburi campus), or KMUTT (Ratchaburi) for short, misunderstand essential concepts in physics. However, investigation on the degree of misunderstanding has never been analysed quantitatively. Therefore, an analysis is required to understand learning achievement of students after finishing the course.

Identifying students' misunderstood concepts is not only a crucial pedagogy, but also a proper approach required for good learning achievement. Various approaches in learning pedagogy are widely studied for effectively assisting knowledge construction of students. Some of these approaches are, for example, application of guided note in lecture [3], collaborative learning [4], and project-based learning. Among these approaches, project-based learning offers many advantages [5-6]. In particular, project-based learning provides a learning environment that accommodates active activities. Also, a well-designed activity could draw students' engagement and assist them to construct knowledge from the interaction with the real world. This advantage, in turn, helps them to generalise ideas into a wide range of situations. Moreover, not only knowledge, but also social interaction can be learnt together among the team members. A project-based approach seems to benefit students for knowledge construction as well as soft-skill development.

For continuous improvement in learning and teaching at KMUTT (Ratchaburi), a project-based activity had been introduced in 2017 to a freshman class as a pilot model for training students. According to a model learning approach [7], a teacher's role also affects students' learning achievement, implying that lecture is also important. Learning and teaching in 2017 for the freshman class was, therefore, an integrated learning approach, complementing the lecture with project activities. The action research in this paper aims to quantify the degree that students understand the topics, in order to improve learning and teaching methods in the future.

2. Methodology and learning approach

Traditional lecture was the main instruction through the course. The lecture for each topic started with the expected learning outcomes. Most students, therefore, knew the scope of assessments. For the selected learning topic of electromagnetism, the following concept was explained to students in class: an electromagnetic (EM) wave, through the entire spectrum, travels at the same speed ($c \approx 3\times10^8$ m/s) through space. The equation had been derived step-by-step in a lecture. Some examples were also provided, and most students gave correct responses to pop-up questions in class.

In a final examination, the question used to assess students' understanding is the following: *Information is sent from earth to a space colony on Mars by two methods, visible light and microwave, at the same time. By which method does the information arrive first on Mars? Also, provide a short explanation to support your answer*. The response is analysed with the rubric scores shown in table 1.

Table 1. Criteria to judge an understanding of the speed of EM wave

Performance	Criteria, judged from each student's response
Misunderstood	One method of sending information is faster than the other.
Understood	The information sent by both methods arrives on Mars at the same time.

In a project activity, students' project concerns with the principle of refraction. The project was designed so that students have to combine multidisciplinary knowledge, in chemistry and physics, to build simple equipment for measuring the percentage of sugar in the syrup of an unknown concentration. The groups of students had to understand the principle of refraction through self-study before they start building their equipment. Each group was working under a supervision of 10 instructors.

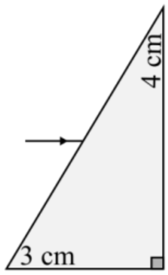

Figure 1. Prism with an incident laser beam.

It was expected that the application of Snell's law and the principle of refraction would be learnt and practiced repeatedly by students during the design process. This activity would replicate an experience of applying knowledge to a real-world problem as well as promoting self-motivation of learning. In a final examination, the question to assess students' understanding is the following: *A laser beam travels from air to a prism of refractive index 1.35, as shown in figure 1. Determine the direction that the laser beam leaves the prism*. Responses are scored by the criteria shown in table 2.

Table 2. Criteria of understanding in the principle of refraction

Performance	Criteria	
	Sketching	Calculation
Misunderstood	• Be unable to sketch any path of the laser beam.	• Be unable to recognise Snell's law.
Partially understood	• Give only one correct path for either the beam inside the prism or the beam exiting the prism. • Provide some, but not all, angles of refraction.	• Recognise Snell's law. • Be unable to apply Snell's law to calculate a refraction angle.
Understood	• Give all correct paths of the refracted laser beam. • Correctly provide all related angles of refraction.	• Recognise Snell's law. • Be able to apply the law to calculate the refraction angle for the exiting laser beam.

3. Results and discussions

3.1. An understanding of the speed of an EM wave

This section presents and discusses students' knowledge about the speed of an EM wave. Figure 2 shows a bar chart of students' understanding on the speed of an EM wave, grouped by students' grades. A dark blue colour represents those who misunderstood, while a bright yellow one represents those who perceived the concept correctly. Only half of students who achieve a high grade of B+ or A correctly recognised the speed of an electromagnetic wave. This ratio is even worse for the students who obtained a low-ranking grade, such as D and D+, as none of them does understand the correct concept for the speed of an EM wave. The proportion of students who understood the concept to the entire population of enrolled students is approximately 18 percent. Alternative learning activities may be required to help students correctly understand the concept.

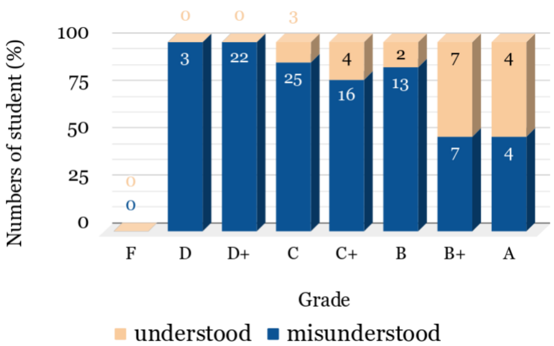

Figure 2. Understanding of the speed of an EM wave.

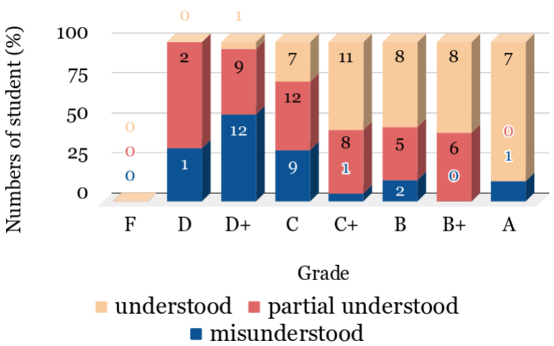

Figure 3. Understanding of the path of refracted light.

3.2. An understanding of the principle of refraction

A degree that students achieve these learning outcomes is analysed after the final examination. Students' understanding on how to sketch the path of light, grouped by students' grades, is shown in figure 3. Each grade is classified into three categories: misunderstood (dark blue), partially understood (red), and understood (bright yellow), based on the degree that students' understanding the refraction concept. The groups of high-ranking grade (A, B+, and B) consist, at a largest proportion, of students who understand how to draw the path of refracted light based on knowledge in physics. The proportion decreases toward a low-ranking grade.

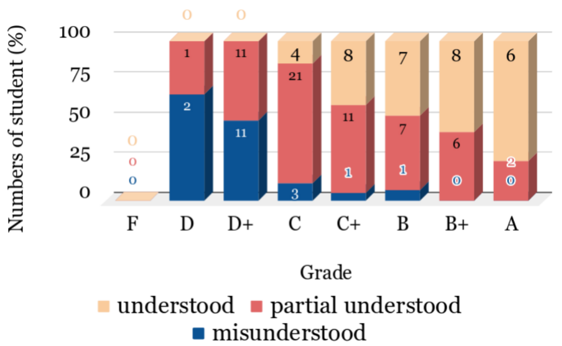

Figure 4. Understanding of the angle of refraction.

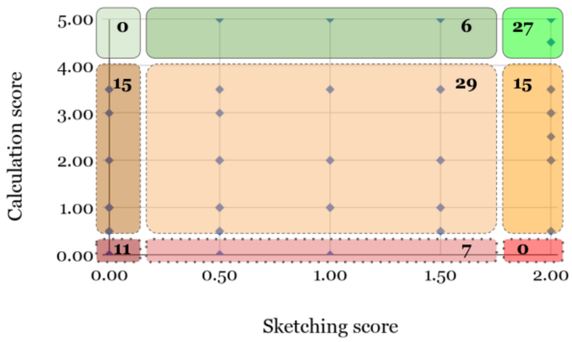

Figure 5. Scatter plot between sketching score and calculation score.

Figure 4 shows an understanding on how to apply Snell's law, grouped by students' grades. Each group of grade is classified into three categories: misunderstood, partially understood, and understood. For each group of high-ranking grades (B, B+ and A), the proportion of students who are able to apply Snell's law is larger than or equal to that of who partially understood. The proportion of those who partially understood or misunderstood the concept increases as the grade decreases from A to D.

Further analysis is performed using the scores obtained from the sketching test and those from the calculation test as shown in figure 5. The horizontal axis represents the sketching scores, and the vertical axis represents the calculation of refraction angle scores. The plot is categorised into nine groups, shown in different rectangular regions. The number of students who belong to the group shows in the rectangle. The top-right group (27 students or 24.5 percent) of the figure is those who do understand how to sketch the path of refracted light and correctly determine the angles of refraction by applying Snell's law. The middle-right group (15 students) is those who understand how the beam of light travels and refracts in different media. They, however, may recognise but are unable to apply Snell's law. Further practice may be required to promote their understanding. The bottom-left group (11 students) and the bottom-middle group (7 students) are those who have low scores. They partially understood or even misunderstood the concepts related to the principle of refraction and Snell's law. The middle group contains the largest proportion of students (29 students or approximately 26.4 percent of all students). The students in this group are partially understood the concepts of Snell's law and the principle of refraction. The middle-left (15 students) and the top-middle (6 students) groups are perhaps most interesting groups in this analysis. These groups of students are able to apply Snell's law without fully understand how the beam of light is incident and refracted on different materials. Students in these groups might have learned the concept of refraction by only memorising and repeating a standard calculation procedure. They, however, may not recognise the implication of the refraction principle.

Beside those who are in the top-right group, it seems that remaining students require time to achieve a full understanding of the topic. A self-learning system and a quick response may be required before the final exam to help students to gain more understanding of the refraction concept. Different approaches may be required for efficiently delivering a body of knowledge to different groups of students.

3.3. Discussion on the learning approaches applied in this action research

Based on the results from the previous section, a project activity leads to a greater number of students who achieved satisfactory levels of knowledge than does the conventional lecture. Given a project, approximately 24.5 percent of students are able to sketch and calculate the refraction of light. In contrast, given the lectures alone, approximately 18 percent of students are able to do so. This finding suggests that active activities introduced to the class can draw students' interest and focus their study in a given topic. The difference of approximately 6 percent in the proportions, however, may not come solely from the project activity. Because the topic had been taught in high schools, many students may already have good prior knowledge in the principle of refraction. Furthermore, the class activities had not been designed to compare learning effectiveness. The project-based activity in this action research was aimed particularly to assist students to be familiar with application of multidisciplinary knowledge, in chemistry and physics, and to apply a new learning pedagogy at KMUTT (Ratchaburi).

4. Conclusion

Learning achievements in fundamental university physics of engineering freshmen, enrolled in 2017 at KMUTT (Ratchaburi), are presented in this paper. Two essential concepts, the speed of an EM wave and the principle of refraction, are chosen to be compared and discussed. These concepts had been delivered to students through different learning approaches. Traditional lecture had been conducted for learning and teaching in most topics. The project-based activity had been assigned, in addition, in the topic of the principle of refraction. The activity aimed for delivering a real-world experience and for introducing an alternative learning approach to the class.

The preliminary analysis yields similar results in both selected topics. Each group of high-ranking grades (B, B+ and A) has more number of students who well understood the concepts of physics. Approximately 18 percent of students perceived the correct concepts in the speed of an EM wave. The number is slightly higher (approximately 24.5 percent) in the evaluation of understanding of the principle of refraction. A high percentage may be accounted by the project activity. However, more study and repetition are required to generalise the conclusion and confirm the beneficial effect of the project.

Regarding an understanding of the principle of refraction, students' responses are classified into nine groups based on their sketching and calculation scores. From the findings, some students demonstrate a partial understanding in the calculation, but they cannot sketch the correct path of the light beam. Those students may remember the principle of refraction but are unable to apply it. Further investigation is needed to understand the learning behaviour of students across different groups, ranging from the group that can master the concepts to the group that still misunderstand them.

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