Activities on reflection of light based on low-cost materials at eighth grade

A Kittiravechote* and N Thinarat

Program of General Science, Faculty of Education, Bansomdejchaopraya Rajabhat University, Bangkok, 10600, Thailand

*Corresponding author's e-mail address: aungtinee.ki@bsru.ac.th

Abstract. Studying science through hands-on activities within the context of teaching and learning using local environments and resources has been recognized as a fundamental prerequisite of school curriculum in many developing countries, including Thailand. Accordingly, we are interested in implementing such a concept in designing science teaching and learning for middle school students that emphasizes student participation in the provision of materials and equipment for scientific activities. The purposes of this study are to design hands-on activities for eighth grade students on the topic of light reflection using low-cost materials, and then to examine the results after they are implemented. The experimental group consisted of 30 eighth grade students who were chosen at random in one room. The instruments used in the experiment were two types of achievement tests that were administered as pretests and posttests on the topics of light reflection on smooth and curved surfaces. The paired sample t-test was performed after the collection of data to determine students' conceptual understanding. Our result displays a highly significant difference ($p < .01$) between the pretest score (39.7%) and posttest score (83.3%), indicating that students actively participated in hands-on activities and learned light reflection knowledge and skills through interaction and discussion with their classmates. We highlight the advantages of our study for science teachers in rural schools in ensuring students develop 21st Century Skills, which is an important part of STEM education.

1. Introduction

Participation and understanding of scientific processes are at the heart of science education [1]. The successful laboratory use is a requirement in science education, as science is an experimental, analytical, and laboratory-oriented discipline that provides a variety of benefits, including the acquisition of basic laboratory skills, the development of observational skills, the explanation of a specific concept, and the most authentic taste of what true science entails [2,3]. However, providing well-equipped labs appears to be one of the main roadblocks to the popularization of science education in low-income schools with limited resources. As a result, methods for improving the current situation in science laboratories include sponsoring various low-cost activities or training teachers to make the most of locally available tools for science teaching [4].

In this work, we are interested in designing and implementing hands-on activities on the topic of light reflection on smooth and curved surfaces using low-cost materials for 30 eighth-grade students. We used a randomized group: pretest and posttest design for educational experimentation. The effect on student achievement was examined using assessments that included a pretest, a posttest, and the difference between the two mean scores. A statistical test, the paired sample t-test, was used to evaluate the significance of the difference in average changes.

2. Research design

Our research was carried out in the following manner. (1) Preparation of the tests. We created two sets of multiple choice test items for light reflection on smooth and curved surfaces, which were adapted from Thai standardized achievement tests and represented Bloom's understanding, comprehension, and application, or related to arithmetic skills and data interpretation obtained through laboratory experiments [5]. Experts first qualified the desirable items in terms of content correctness and item-objective congruence index, and then a test-re-test technique was used to exclude incorrect questions in terms of difficulty index and discriminant index. Finally, five questions from each set were chosen as the pretest and posttest; note that the pretest and posttest were identical but alternate choices. (2) Designing activities with low-cost materials. We used activities based on light reflection, ranging from smooth to curved surfaces, as shown in figure 1. Figure 1 (A) depicted the transformation of a smartphone into a pseudo-hologram projector by demonstrating the concept of light reflection on a smooth surface using a plastic transparent frustum [6]. Figure 1 (B) displayed how a metal curved surface made from an unused soft drink can was used to demonstrate light reflection on the curved one [7]. (3) Running the pretest. We decided to perform an experiment in education using a randomized group: pretest and posttest design. In this study, 30 eighth grade students were randomly assigned to the experimental group in one room. (4) Implementation of the treatment. The experimental group was introduced to light reflection activities with low-cost materials using the modified 5E steps lesson plan shown in table 1. (5) Running the posttest. (6) Conducting the statistical inferences. The difference between the pretest and posttest was measured as an average. The paired sample t-test was used to assess the statistical significance of the difference in average changes.

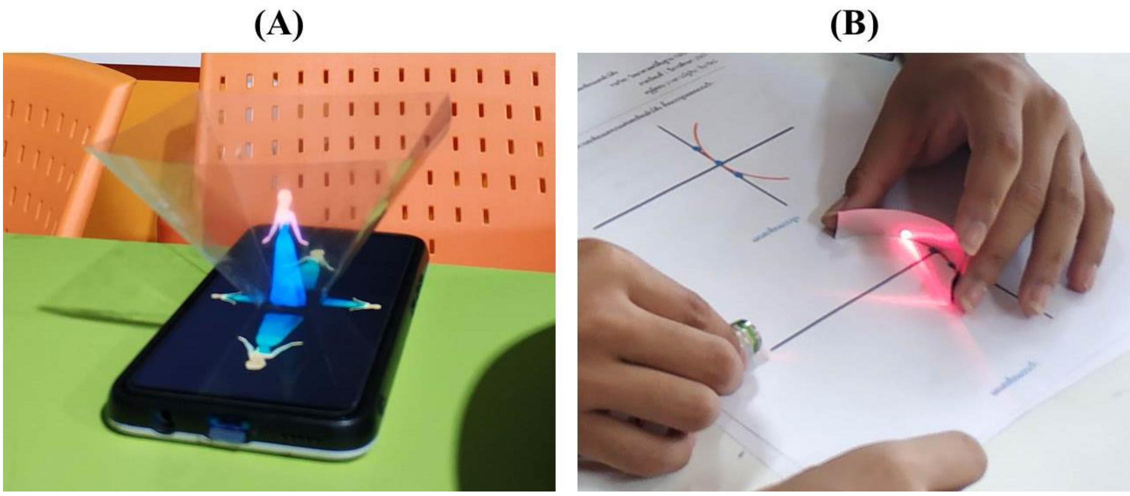


Figure 1. (A) Demonstration of light reflection on a smooth surface called pseudo-hologram: a hologram channel on YouTube was accessed via a plastic frustum mounted on the screen of a cell phone. (B) Experiment with the theory of light reflection on a curved surface: the remaining soft drink can was used to project a laser beam onto a curved metal plate.

Table 1. Lesson plans for light reflection using the modified 5E steps.

	Period 1 (50 min) Light reflection on a smooth surface	Period 2 (50 min) Light reflection on a curved surface
Warm up (3 min)	Students are introduced to the activity and lesson. Pairs of students are assigned to work together.	Students are introduced to the activity and lesson. Pairs of students are assigned to work together.
Introduction (10 min)	Students make the pseudo-hologram.	Students shine a laser light onto a curved surface and draw the incident ray and reflected ray.
Body (25 min)	Teacher demonstrates how to create a virtual image using light rays. Students discuss how to create image of the pseudo-hologram with their partner. Students give the presentations.	Teacher recalls the law of reflection. Students discuss how to find the focal point of a concave and convex mirror with a partner. Students give the presentations.
Closing (10 min)	The main idea of the lesson is summarized by all students. As light strikes a smooth surface, (i) the angle of incidence equals the angle of reflection (ii) the incident ray, reflected ray, and normal line are all in the same plane. Since the tails of light rays converge, the image obtained from a smooth surface is a virtual image. The visual image that appears within the pseudo-hologram can be seen from all lateral sides.	The main idea of the lesson is summarized by all students. An incident light is reflected according to the law of reflection at every point along the curved surface. As light that is parallel to the principal axis strikes the concave mirror, the reflected light gathers at a point known as the (real) focal point. As light that is parallel to the principal axis strikes the convex mirror, the reflected light diverges. However, if the tails of light rays are drawn indefinitely, a point of intersection known as the (virtual) focal point is discovered.
Exit ticket (2 min)	Assign students to write what they have learned today	Assign students to write what they have learned today

3. Result

Table 2 displays measures of central tendency by arithmetic mean from the pretest and posttest of light reflection on smooth and curved surfaces. The pretest and posttest mean scores are 3.97 (=39.7%) and 8.33 (=83.3%), respectively. The difference between the two mean scores is 4.36, indicating that activities conducted with low-cost materials had a positive effect on student achievement.

Table 2. Pretest and posttest arithmetic mean measures of central tendency.

No.	Pretest score	Posttest score	No.	Pretest score	Posttest score	No.	Pretest score	Posttest score	No.	Pretest score	Posttest score
1	2	7	**9**	3	7	**17**	9	10	**25**	3	8
2	6	10	**10**	2	7	**18**	8	10	**26**	4	10
3	3	7	**11**	2	8	**19**	4	8	**27**	6	10
4	4	7	**12**	2	7	**20**	2	9	**28**	4	9
5	5	10	**13**	2	8	**21**	3	9	**29**	4	10
6	5	8	**14**	4	7	**22**	4	7	**30**	4	9
7	4	8	**15**	5	9	**23**	3	7	**Sum**	**119**	**250**
8	6	9	**16**	2	7	**24**	4	8	**Mean**	**3.97**	**8.33**

Furthermore, as shown in table 3, the paired sample t-test score of students is used to determine the significance of the difference in average changes between the pretest and posttest. We begin by using the boxplot to examine the distribution of our differences. As long as the shape isn't too skewed and there aren't any outliers, the inference problem for paired data is simply a one-sample problem on the difference within each pair. Later, we established the null hypothesis: mean(Posttest) – mean(Pretest) = 0, and the alternative hypothesis: mean(Posttest) – mean(Pretest) > 0. Following the calculation, we discovered that our t-value was 18 with 29 degrees of freedom. Regarding the table with 29 degrees of freedom, our obtained value (18) exceeds the given value for both .05 level (1.699) and .01 level (2.462). As a result, the null hypothesis is rejected, and the significantly greater of the two means' differences than the test difference (0) is accepted. Therefore, the use of low-cost materials in science education was deemed a success overall.

Table 3. The significance of the difference in average changes between the pretest and posttest was indicated by the students' paired sample t-test score.

No.	*D*	d^2	No.	*D*	d^2	No.	*D*	d^2	No.	*D*	d^2
1	5	0.3969	**9**	4	0.1369	**17**	1	11.3569	**25**	5	0.3969
2	4	0.1369	**10**	5	0.3969	**18**	2	5.6169	**26**	6	2.6569
3	4	0.1369	**11**	6	2.6569	**19**	4	0.1369	**27**	4	0.1369
4	3	1.8769	**12**	5	0.3969	**20**	7	6.9169	**28**	5	0.3969
5	5	0.3969	**13**	6	2.6569	**21**	6	2.6569	**29**	6	2.6569
6	3	1.8769	**14**	3	1.8769	**22**	3	1.8769	**30**	5	0.3969
7	4	0.1369	**15**	4	0.1369	**23**	4	0.1369	**Sum**	**131**	**50.967**
8	3	1.8769	**16**	5	0.3969	**24**	4	0.1369	**Mean**	**4.37**	

Note: D = Posttest score - Pretest score

$d = D - \text{Mean of } D = D - 4.37$

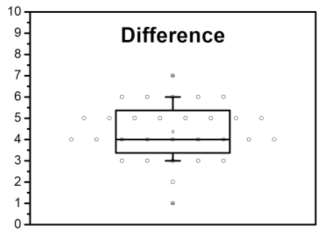
$d^2 = (D - 4.37)^2$

$$S.D. = \sqrt{\frac{\sum d_i^2}{n-1}} = \sqrt{\frac{50.967}{30-1}} = 1.33$$

$$t = \frac{\overline{D}}{S.D./\sqrt{n}} = \frac{4.37}{1.33/\sqrt{30}} = 17.99 \approx 18$$

Degree of freedom = 30 – 1 = 29

Boxplot of the difference



4. Discussion

We investigated whether activities with low-cost materials developed to teach concepts related to the reflection of light unit could contribute to high levels of science achievement for students, as well as students' understanding of science concepts and academic achievement. Multiple-choice tests were used as data collection tools to determine students' conceptual understanding. We found that there is a highly significant difference ($p < .01$) between the pretest and posttest results, according to the results of the question-based achievement score analysis of the pretest (39.7%) and posttest (83.3%).

After reviewing the student worksheet, we discovered that starting the class with a practice or an experiment can help the children visualize and understand further. For example, for the reflection of light on a smooth surface shown in figure 2, (i) students were instructed to work in pairs to construct the pseudo-hologram, (ii) the teacher taught students how to draw the rays of light on the smooth surface (figure 2 (A)), (iii) the teacher allowed students to work and discuss in pairs to draw light rays that created a virtual image on the pseudo-hologram (figure 2 (B)), (iv) the teacher then chosen students to present their findings in front of the class, and (v) the teacher employed leading questions to summarize the main idea of the science lesson. Likewise, such activity before concept was repeated in our class for the reflection of light on a curved surface, as shown in figure 3. Students were tasked with determining the focal point of the curved surfaces by incident and reflection of laser beams from the concave (figure 3 (A)) and convex mirrors (figure 3 (B)). As evidenced by worksheet samples, students can solve unfamiliar problems by applying abstract content knowledge to explain unknown phenomena, which is key science process skill that teachers seek to foster.

(A) **(B)**

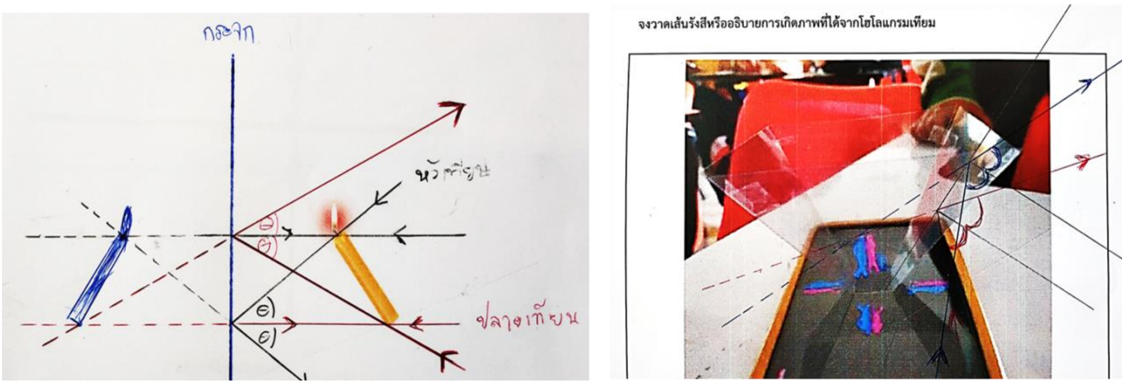


Figure 2. (A) Students practice drawing the light ray to create a virtual image. (B) Students discuss and report on how the image in the pseudo-hologram is formed with a partner.

(A) **(B)**

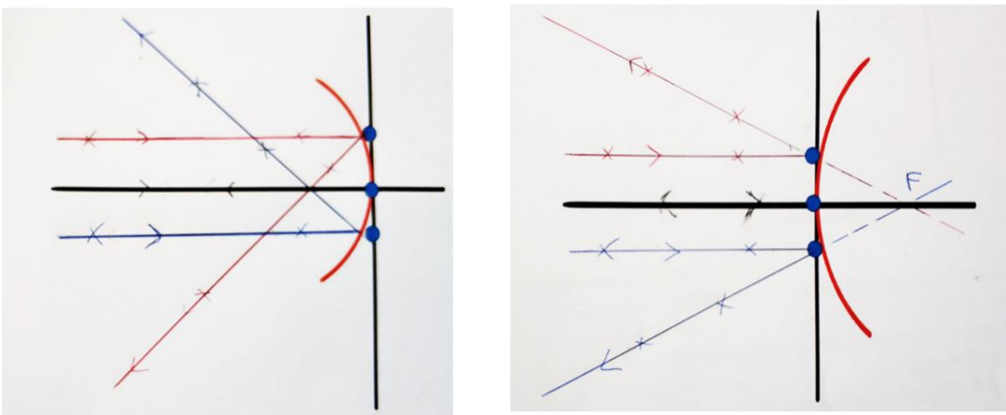


Figure 3. By shining a parallel laser light on a curved surface, the focal point of concave and convex mirrors can be determined. (A) A concave mirror serves as a focal point in front of the mirror, allowing light to converge. (B) A convex mirror provides a focal point behind the mirror to diverge the light.

In addition, educators strongly advise students to engage in hands-on activities in science classes. Many hands-on activities have the ability to greatly influence students' engagement in the activities because they are one situational factor that is often thought to elicit students' interest and inspire them to learn science [8], which are in good agreement when we perform the lesson, as shown in figure 4. The majority of observational findings support the hypothesis that engaging in hands-on tasks contributes to positive motivational results [9]. Moreover, it is not surprising that the students in our experiments have higher posttest scores than pretest scores, given that previous studies show that students who engage in hands-on studies have a higher GPA, complete more science courses, and have a greater willingness to pursue STEM degrees [10]. Our research backed up this conclusion, claiming that the effect is most likely due to the active design of the integrated instruction discussed earlier. We conclude that our activities, which were conducted with low-cost materials, had a positive impact on student achievement and could provide an opportunity for students in rural areas to experiment.

(A) **(B)**

Figure 4. In the beginning of science class, students participated in hands-on activities on light reflection on a smooth surface (A) and a curved surface (B), which drew their attention to the next step, the discussion and report stages.

5. Conclusion

We have demonstrated how low-cost materials can be used in science hands-on activities to provide purposeful and meaningful experiences for eighth graders. Activities based on low-cost materials, in particular, improve conceptual understanding of light reflection on smooth and curved surfaces, resulting in substantially higher mean posttest scores than pretest scores at the .01 level. The findings of this study show that enabling students to perform science experiments with low-cost materials has a positive effect on their interest in those subjects and related skills.

Acknowledgements

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