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Hands-on Optics Learning Through a Pinhole Camera Experimental Activity

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ABSTRACT

This study investigates the effect of a hands-on pinhole camera activity on junior high school students' motivation in learning light and optics. The study employed a descriptive research design implemented through a practicum-based learning activity within a Research-Based Learning (RBL) extracurricular program. Participants consisted of 18 students in Grades 7 to 9 who constructed and experimented with a pinhole camera to observe image formation by varying the distance between the pinhole and the screen. Data were collected through student worksheets and a motivation questionnaire using a five-point Likert scale. The results show that students consistently observed inverted images and systematic changes in image sharpness and size, indicating that the pinhole camera activity effectively represented key principles of image formation and rectilinear light propagation. Descriptive analysis of motivation data revealed high motivation during the hands-on activity and moderate motivation after learning. Students identified direct experimentation and observation as the most meaningful aspects of the learning experience. These findings suggest that hands-on pinhole camera activities can support meaningful optics learning by promoting conceptual understanding and enhancing students' situational motivation in science learning.

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INTRODUCTION

Light and image formation are phenomena that students encounter frequently in everyday life. Experiences such as seeing reflections in mirrors, taking a picture with a camera, and perceiving images with human eyes seem familiar, yet the mechanisms are not directly visible and require abstract reasoning. Understanding how images are formed requires concepts such as the straight-line propagation of light, geometric relationships between objects and apertures, and the formation of images in space (Learning Lumen, 2021). Without a clear understanding of these concepts, students often observe images without being able to explain how or why they are formed. This condition illustrates a persistent issue in optics learning, where students often lack conceptual knowledge in optics learning (Sebald et al., 2022).

This difficulty is well documented in physics education research. Diagnostic research by Putri et al. (2024) shows that students often misunderstood key concepts related to vision, the properties of light, and image formation when learning about light and optics. Such misconceptions are closely linked to instructional approaches that rely heavily on textbooks and provide limited opportunities for hands-on learning. In the current government-issued science textbook, explanations of light properties and image formation in the camera and the human eye are presented briefly and are not supported by clear ray diagrams. As a result, students receive fragmented explanations that are difficult to connect with observable phenomena. In addition, classroom instruction often lacks contextual learning that relates optics concepts to students' everyday experiences (Putri et al., 2024). Whereas, Affriyenni et al. (2023) suggest in her research that students develop stronger conceptual understanding when they actively engage in investigations that involve solving real or situational problems. Therefore, there is a need for effective learning media that can support meaningful learning in optics.

Previous studies have therefore focused on developing learning media to support students' understanding of optics concepts. For example, Azmy et al. (2020) implemented Android-based comics as supporting media for learning optics and found that students were able to identify and analyze the parts of the eye and camera more effectively after instruction. The use of this media also contributed to improvements in students' critical thinking skills. Similarly, Widiasih et al. (2023) employed augmented reality to teach the optical system of the human eye through interactive visualizations. Their study reported positive results, with students indicating that augmented reality made it easier to understand eye optics concepts. These studies demonstrate that innovative learning media can enhance students' understanding and engagement in optics learning.

However, much of the existing media is digital and focuses primarily on visualization rather than direct physical experience. While digital tools offer visual support, learning media that allow students to directly observe optical phenomena are also important because they enable students to engage with concepts in a concrete, non-simulated way (Gire et al., 2008, as cited in Tseng et al., 2023). This condition highlights the need for learning media that allow students to interact directly with optical processes and observe their effects without relying solely on simulations.

One instructional approach that meets this need is the construction of a pinhole camera in learning optics. A pinhole camera is a simple optical instrument that forms images without using a lens or a mirror. It consists of a light-proof hollow box with a small aperture on one side and a semi-transparent screen on the opposite side. When light from an illuminated object passes through the aperture, it travels in straight lines and forms a real, inverted image on the screen, demonstrating the principle of rectilinear propagation of light (Pandey, 2024). Through this activity, students learn how images are formed and how the behavior of light contributes to image formation.

In addition, the pinhole camera provides a meaningful basis for comparing optical instruments with the human eye. During this activity, students encounter an inverted image (Pandey, 2024), which contrasts with their everyday visual experiences. This unexpected result motivates students to think critically and seek explanations for why their observation differs from what they normally see (Ma, 2023). Such situations can stimulate reasoning and support deeper understanding of how images are formed.

Beyond conceptual understanding, the hands-on construction of a pinhole camera is expected to influence students' motivation to learn science. By actively engaging in the learning process, students may experience greater interest in the learning process, enjoyment, and a sense of contribution to higher levels of learning satisfaction (Ma, 2023; Oje et al., 2021). These motivational aspects are important for fostering sustained engagement in science learning. Therefore, examining students' motivation within the context of a hands-on discovery learning activity provides valuable insights into how instructional design can support motivational outcomes in science education.

Based on the considerations above, this study aims to investigate the effect of hands-on learning activities in teaching light and optics through the construction of a pinhole camera on students' motivation in science learning. To achieve this aim, the following research questions were determined.

1. How does the hands-on pinhole camera activity represent the process of image formation in light and optics learning?
2. How do students perceive and respond to learning light and optics through the hands-on pinhole camera activity in terms of motivation and learning experience?

In accordance with the junior high school science curriculum, the learning activity developed in this study is aligned with the relevant Core and Basic Competencies related to light and optical instruments. The Core and Basic competences addressed in this study are presented in Table 1. below.

Table 1. Core Competences and Basic Competences

Core Competence 3 (Cognitive)	**Core Competence 4 (Psychomotor)**
3. Understanding knowledge (factual, conceptual, and procedural) based on curiosity about science, technology, art, and culture related to observable phenomena and events.	4. Trying, processing, and presenting in the concrete domain (using, decomposing, assembling, modifying, and creating) and in the abstract domain (writing, reading, calculating, drawing, and composing) in accordance with what is learned at school and from other sources with the same perspective or theoretical framework.
Basic Competence 3 (Cognitive)	**Basic Competence 4 (Psychomotor)**

3.12 Analyzing the properties of light, the formation of images on flat and curved surfaces, and their applications in explaining the process of vision in the human eye and insects, as well as the working principles of optical instruments.	4.12 Presenting the results of experiments on vibrations, waves, and sound; and presenting the results of experiments on image formation using mirrors and lenses.

METHOD

Research Design

This research used a descriptive research approach combined with an experiment-based practicum activity to investigate students' motivation in learning light and optics through the construction and use of a pinhole camera. The practicum was designed to provide students with direct experience in observing image formation which allow them to explore the optical principles through a hands-on experimentation

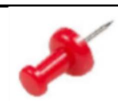
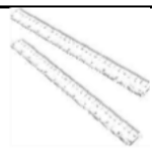
Participants

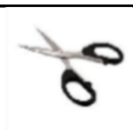
The participants in this study were junior high school students in Grades 7 to 9 who took part in an Research-Based Learning (RBL) extracurricular program at a junior high school. A total of 18 students participated in the study on a voluntary basis. The students attended weekly RBL sessions and had basic prior knowledge of general science concepts. The practicum was implemented during a regular extracurricular schedule and conducted over a 90 minutes session.

Learning Activity: Pinhole Camera Construction and Investigation

The learning activity involved the construction and testing of a simple pinhole camera as a learning medium for understanding image formation. The students are randomly divided into small groups consisting of 3 to 4 people to assemble the camera. The tools and materials used in the practicum are listed on Table 2. below.

Table 2. Tools and materials for the pinhole camera practicum

Tools' Name	Amount	Tools' Name	Amount
 1. Cardboard boxes	2 set	 6. Nail/push pin/pin	1 piece
 2. Black tape	1 roll	 7. Ruler	1 piece

	1 sheet		1 piece
3. Paper		8. Markers	
 4. Oil		 9. Scissors	1 piece
 5. Tissue paper	1 sheet		

When creating the pinhole camera, students follow the instructions that are listed on Figure 1. below. The procedures are in accordance with the Worksheet that they use. In this practicum, the aspects being measured are the sharpness and size of the image formed inside the pinhole camera.

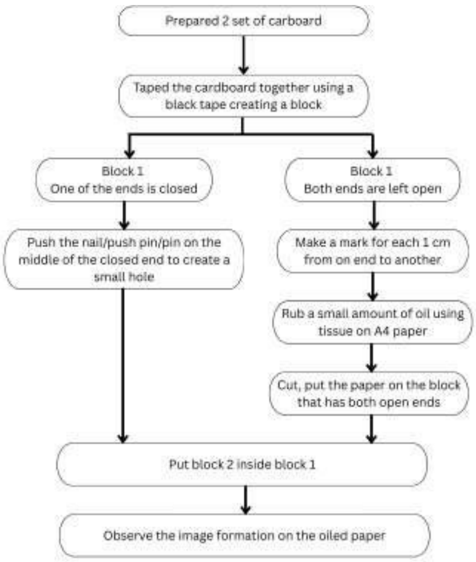


Figure 1. The flowchart of pinhole camera practicum worksheet

After construction, students conducted an experiment by systematically varying the distance between the pinhole and the screen while observing the image formed. For each variation, students recorded the sharpness and clarity of the image. This process enabled students to directly observe the relationship between light propagation and image formation.

Variables

The variables in the particum experiment were defined as follows

1. Independent variable: Distance between the pinhole and the screen.

2. Dependent variable: Sharpness of the image formation on the screen.
3. Controlled variables: Type of the semi-transparent screen.

Data Analysis

Data from the worksheets were analyzed descriptively to identify patterns in students' observation of image formation. Questionnaire responses were analyzed using descriptive statistics to examine students' motivation toward learning light and optics through the hands-on practicum activity.

RESULTS AND DISCUSSION

RQ 1: How does the hands-on pinhole camera activity represent the process of image formation in light and optics learning?

The data based on the observation that has been done by the students is presented in Table 3. below.

Table 3. Data Analysis

Distance Category	Distance Range (cm)	Image Characteristics Observed
Short distance	4-6	Image appears inverted; color visible; image very clear but relatively small
Medium distance	9-15	Image remains inverted; image becomes clearer and larger; sharpness improved
Long distance	16-22	Image is formed but appears less sharp or slightly blurred; image size become larger
Very long distance	≥ 26	Image is formed but unclear or difficult to observe; image size is the largest

The result on Table 3. shows that the hands-on pinhole camera activity effectively represents the process of image formation. It shows that students consistently observed that images formed through the pinhole were inverted and that image sharpness varied with the distance between the pinhole and the screen.

Figure 2. The construction of the pinhole camera

At short distances, students reported images that were inverted, clearly visible, and relatively small. At medium distance, image sharpness improved and images appeared clearer and larger. At longer distances, images were still formed but became less sharp or blurred, and at very long distances some groups reported that the image was unclear or not observable. These findings indicate that students were able to identify systematic changes in image clarity as a result of manipulating a single experimental variable.

Figure 3. The image formed on the pinhole camera

The observed patterns can be explained by the principle of rectilinear propagation of light . The formation of inverted images occurs because light rays travel in straight lines and intersect at the pinhole before reaching the screen. Furthermore, changes in image size and sharpness reflect the geometric relationships among the object, the aperture, and the screen position (Pandey, 2024). By directly observing these effects, students were able to connect their experimental findings with fundamental optics principles, reinforcing their understanding of image formation mechanisms.

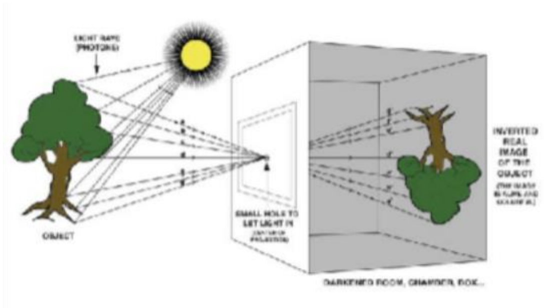


Figure 4. Image formation principle of a pinhole camera

These results also indicate that the pinhole camera activity supported students in linking abstract theoretical concepts with observable physical phenomena. The opportunity to manipulate variables and directly observe changes in image formation allowed students to develop a concrete understanding of light behavior without relying on lenses or mirrors. This finding is consistent with previous studies that emphasize the role of hands-on experimentation in strengthening conceptual understanding in physics learning.

RQ 2: How do students perceive and respond to learning light and optics through the hands-on pinhole camera activity in terms of motivation and learning experience?

To facilitate the interpretation of students' motivation scores, predetermined score intervals were established based on the characteristics of the five-point Likert scale used in the questionnaire. The construction of the intervals in this study was based on the procedure developed by Alkharusi (2022) in his article entitled "A descriptive analysis and interpretation of data from Likert scales in educational and psychological research". The Likert scale ranged from 1 (strongly disagree) to 5 (strongly agree). The scale range was divided into three equal categories representing low, moderate, and high levels of motivation.

The width of each interval was calculated by subtracting the minimum possible score from the maximum possible score and dividing the result by the number of categories. Accordingly, the interval width was calculated as follows:

$$\frac{5-1}{3} = 1.33$$

Based on this calculation, the following score intervals were used to classify students' motivation levels: mean scores ranging from 1.00 to 2.33 were categorized as low motivation, scores ranging from 2.34 to 3.67 were categorized as moderate motivation, and scores ranging from 3.68 to 5.00 were categorized as high motivation.

Table 4. Descriptive Statistics of Students' Motivation During and After the Hands-on Learning Activity

Aspect	Descriptive Statistics		Std. Deviation
	N	Mean	
During Learning	18	3.83	.615
After Learning	18	3.39	.348

Table 4 presents the descriptive statistics of students' motivation during and after the hands-on learning activity involving the construction of a pinhole camera. The results show that the mean motivation score during learning was 3.83 (SD = 0.615), while the mean motivation score after learning was 3.39 (SD = 0.348).

Based on the predetermined score intervals for a five-point Likert scale (1.00–2.33 = low, 2.34–3.67 = moderate, 3.68–5.00 = high), the mean motivation score during learning falls into the high motivation category. This indicates that students demonstrated a strong level of motivation while actively engaging in the hands-on activity. The relatively larger standard deviation suggests some variability in students' motivational responses during the activity, which may reflect differences in engagement levels or learning preferences among students.

In contrast, the mean motivation score after learning is categorized as moderate motivation (mean = 3.39). Although students remained positively motivated following the completion of the activity, the decrease in the mean score suggests that the heightened motivation experienced during the hands-on process was not fully sustained after the activity ended. The smaller standard deviation indicates more consistent motivational responses among students after learning. These results indicate that students experienced the highest motivation when actively engaged in the hands-on practicum, while motivation become more uniform after the activity.

Table 5. Students' Perceptions of Meaningful Aspects of the Pinhole Camera Activity

No	Statements	Percentage (%)
1	When trying out the constructed pinhole camera and observing	73.33
	the results obtained.	
2	When designing and constructing the pinhole camera	20
3	The entire activity process was meaningful	6.67

Further analysis of students' learning experiences revealed that most students (73.33%) perceived testing the pinhole camera and observing the image formation as the most meaningful aspect of the activity (Table 4). A smaller proportion of students (20%) identified the design and construction process as the most meaningful, while 6.67% perceived the entire activity as equally meaningful. These findings suggest that direct observation of optical phenomena played a key role in shaping students' positive learning experiences.

Figure 5. The image observation process

In general, the results indicate that students responded positively to the hands-on pinhole camera activity in terms of both motivation and learning experience. The practicum effectively supported situational motivation during active engagement and provided meaningful learning experiences by allowing students to directly observe image formation in a concrete, non-simulated manner.

CONCLUSIONS AND SUGGESTIONS

Conclusions

Based on the findings in this study, it can be concluded that hands-on learning activities through the construction and use of a pinhole camera are effective in representing the concept of image formation in light and optics learning. Students were able to observe the formation of inverted images as well as changes in image sharpness and size resulting from variations in the distance between the pinhole and the screen. Additionally, the activity also enhanced students' learning motivation, particularly during the learning process. Students responded positively to learning experiences that involved direct observation and concrete exploration of optical phenomena. Therefore, the use of a pinhole camera as a learning media can serve as an effective alternative for supporting meaningful, student-centered optics learning.

Suggestions

Based on the results of this study, it is recommended that teachers incorporate simple hands-on activities such as the pinhole camera into light and optics instruction, particularly to help students develop a concrete understanding of image formation concepts. This activity may be integrated into inquiry-based or practicum-oriented learning to increase student engagement and motivation. Future research is encouraged to examine the effects of pinhole camera activities on students' conceptual understanding using quantitative approaches or to compare hands-on learning with digital learning media. Additionally, further studies involving larger samples or implementation in formal classroom settings are suggested to provide more comprehensive insights.

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