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[Research Article]

Experimental Design of Shadow Formation in Optical Devices with 2D Algodoo Simulation

***Rachmad Resmiyanto*[1]*, Novi Ayu Lestari*[2]**

[1]*Pendidikan Fisika, FITK, UIN Sunan Kalijaga, Yogyakarta*
[2]*SMA Negeri 1 Anyer, Kota Cilegon, Banten*
E-mail: rachmad.resmiyanto@uin-suka.ac.id

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ABSTRACT

The process of image formation in optical instruments such as the eye, magnifying glass, microscope, telescope, and camera is an important part of learning geometric optics. These concepts are often considered difficult and abstract by students, as the path of light and the process of image formation cannot be directly observed. The conceptual experimental method is used to identify the physical concepts in optical phenomena and translate them into 2D simulations in Algodoo. This study consists of three steps: (1) designing an experiment using Algodoo to model the image formation phenomenon, (2) configuring optical instruments, light sources, rays, and lenses to achieve image formation that aligns with its physical concepts, and (3) conceptually analyzing the simulation results and observing students while using the simulation. The results of the study show that this image formation experiment can be easily understood by students. This is evidenced by the fact that students were able to independently conduct the image formation simulation. Therefore, it can be concluded that the 2D simulation software Algodoo can be used effectively to design image formation experiments in optical instruments.

Keywords: experiment, Algodoo, optical instruments, image.

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1. INTRODUCTION

Learning about the formation of shadows on optical devices, such as the eye, lup, camera, telescope, and microscope, is an important part of the topic of geometric optics in physics. This material is taught from junior high school to university level, with a special emphasis on class XI at the senior high school level in accordance with Curriculum 2013. Understanding how shadows are formed on these optical devices helps students understand the basic principles of how light interacts with lenses and mirrors to produce images.

However, these concepts are often considered difficult and abstract by students, because the path of light and the process of shadow formation cannot be observed directly (Wulandari, et al., 2022). The issue of concepts in physics learning is indeed an important issue (Rahayu, et al, 2022). Inaddition, students often experience misconceptions related to the nature of the shadowsformed, the position of the shadows, and the effects produced by various types of lenses and mirrors on different optical devices (Hasibuan and Hasibuan, 2023; Ina and Mufit, 2022). Limitations in physics practicum tools in schools also add to the challenge, because not all schools have the facilities to conduct optical experiments with complete tools, such as telescopes and microscopes, making it difficult for students to imagine this phenomenon in real life (Basuki, 2023).

A survey conducted at SMA Negeri 5 Yogyakarta revealed that 79% of students felt that geometric optics material tends to be abstract and difficult to understand. The biggest challenge is faced in understanding the concept of shadow formation produced by mirrors and lenses, with a percentage reaching 55.82%. This was followed by difficulties in understanding the characteristics of shadows (23.26%) and the application of the laws of reflection and refraction (9.30%). On the other hand, physics teachers at the school stated that limited time and facilities often hindered the implementation of practicum, making the explanation of abstract concepts, such as special ray paths, difficult. They also highlighted the importance of using visual aids or animations to help students understand the material.

To address this challenge, the use of computer-based simulations is gaining ground as an innovative solution in physics education. One software that has great potential to support the learning of optical concepts is Algodoo (http://www.algodoo.com/(Gregorcic & Bodin, 2017). Algodoo is a 2D simulation application that allows users to create and control various physics parameters, including light path, lens position, and mirror angle, so that users can see the real effects of these changes in a virtual environment. Algodoo provides more flexibility than other simulation software due to its interactive nature and high customisation, which allows students to design and modify optical experiments as needed (Euler & Gregorcic, 2019). Simulations in Algodoo can provide concrete and intuitive visualisations of shadow formation in various optical devices, helping students understand the mechanisms behind them.

In general, interactive media can improve students' conceptual understanding (Sriyani et all, 2023). Various studies have proven that Algodoo is effective in supporting the physics learning process. Research conducted by Harun Çelik (2015) showed that the use of Algodoo can improve students' understanding, while research by Luki & Kustijono (2017) showed that this tool can develop science process skills. In addition, a study in Brazil also found that students who utilised Algodoo had a better and faster understanding of physics material. However, geometric optics simulations using Algodoo are still relatively limited, and guidelines for its use are not always available, so users need to learn how to operate it independently.

The experimental design of shadow formation on optical devices using 2D Algodoo simulation aims to facilitate students' understanding of the basic concepts of geometric optics. Through this simulation, students can explore the workings of optical devices such as the eye, lup, camera, telescope, and microscope, and understand the role of lenses and mirrors in the formation of shadows. By visually seeing the path of light and the results of shadow formation, students are expected to be able to understand this concept in depth, reduce misconceptions, and improve their critical thinking skills. This research is also expected to contribute in providing innovative and practical technology-based learning methods for schools that have limited optical laboratory equipment, so that the physics learning process becomes more effective and interesting for students.

In general, optical devices are divided into 2, namely natural and artificial optical devices. Natural optical devices, for example, are the human eye. Artificial optical instruments include the lup, microscope and telescope. Optical devices have an important role in everyday life and science. The eye is a natural optical device that captures light and processes it, allowing humans to see objects at various distances and in detail. A lup or magnifying glass is used to see small objects in greater detail by magnifying the image using a single convex lens. They are also useful for reading small print or observing insects and other details in biology. Microscopes meanwhile are more complex, using a combination of objective and ocular lenses to magnify very small objects hundreds or thousands of times, making them vital tools in science for observing cells, bacteria and other microscopic structures in biology and medicine. Telescopes, often used to observe celestial objects, magnify images of distant objects using lenses or mirrors that collect and focus light, allowing astronomers to study planets, stars and galaxies. They utilise the basic principles of light refraction and reflection to help us see details of objects at sizes or distances invisible to the ordinary eye.

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1) Eyes

In the process of focusing light, two very important elements are the cornea and the crystalline lens. The cornea serves as the outer protective layer that refracts or deflects light entering the eye. The crystalline lens, on the other hand, regulates the refraction that occurs due to the fluid in front of the lens. The ability of the lens to adapt, either by bulging or flattening, is known as the accommodation power of the eye.

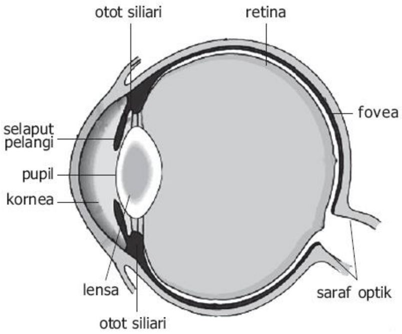


Figure 1. Parts of the eye (Sumarsono, 2009)

Normal Eyes

The near point of the eye, also known as the Punctum Proximum (PP), is the closest distance at which the eye can clearly focus an object. For young adults, this near point is generally at a distance of about 25cm, while children can often focus objects at a distance of up to 10cm. As we age, the accommodation ability of the eye tends to decrease, which causes the near point to become more distant. On the other hand, the far point, called Punctum Remotum (PR), is the furthest distance at which objects can still be seen clearly. For the normal eye, the near point is set at PP = 25 cm, while the far point PR is considered to be infinity.

Myopia

Myopia, also known near-sightedness and short-sightedness, is a condition where the eye can only focus objects at close range. In this case, the far point (Punctum Remotum, PR) is not located at an infinite distance, but rather at a closer

closer, so that distant objects are not clearly visible. Myopia is generally caused by the lens of the eye being too convex, which causes the image of a distant object to fall in front of the retina. To correct this condition, a diverging (concave) lens is used which spreads the light rays in a parallel direction. This allows the incoming rays to be properly focused on the retina.

Hyperopia

Hypermetropia, or better known as farsightedness, is a condition in which the eye is unable to focus on objects that are close. Although distant objects are usually clearly visible, the near point (Punctum Proximum, PP) in hypermetropic eyes is greater than 25 cm, which makes it difficult to read. The main cause of this disorder is the eye lens that is too flat, so that the image of the object being viewed is formed behind the retina. To overcome this problem, a convergent (convex) lens is used which can help focus light precisely on the retina.

2) Lup (magnifying glass)

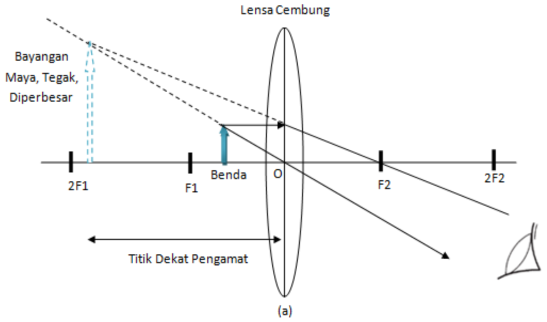


Figure 2. Shadow Formation Process in a Lup with Accommodated Eyes (Sumarsono, 2009)

A lup is an optical instrument consisting of a convex lens that functions to form a virtual, upright, and enlarged image when the object is placed at a distance smaller than the focal distance of the lens. This tool is designed to facilitate the observation of small objects to make them look bigger and clearer. The shadow formation process using a lup can be seen in figure 2 and figure 3. Using a lup, fine details on small objects can be better observed, making it extremely useful in a variety of applications, such as reading small text or observing biological specimens.

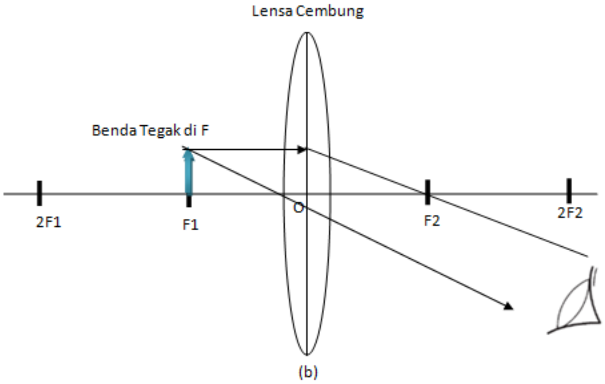


Figure 3. Shadow Formation Process in a Lup with Unaccommodated Eyes (Sumarsono, 2009)

The magnification for the maximum accommodated eye (maximum magnification) is shown by the following equation:

$$M_a = \frac{s_n}{f} + 1 \tag{1}$$

Magnification for the non-accommodating eye (minimum magnification)

$$M_a = \frac{S_n}{f} \tag{2}$$

3) Microscope

A microscope is an optical instrument designed to observe very small objects that cannot be seen by the naked eye. This tool consists of two convex lenses, namely the objective lens which is located close to the object being observed and the ocular lens which is close to the observer's eye. In a microscope, the focal distance of the objective lens is greater than the focal distance of the eyepiece ($f_{ob} > f_{ok}$Using a microscope, fine details on small objects, such as cells or other microstructures, can be observed clearly, enabling more in-depth research in various fields of science. Using a microscope, fine details on small objects, such as cells or other microstructures, can be clearly observed, enabling more in-depth research in various fields of science, including biology and materials science.

Magnification on the objective lens, M_{ob}

$$M_{ob} = \frac{h'_{ob}}{h_{ob}} = \frac{-s'_{ob}}{s_{ob}} \tag{3}$$

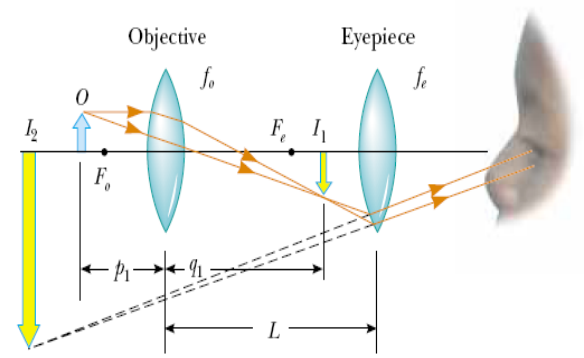


Figure 4. Shadow Formation on a Microscope (Jewet, 2004)

Distance of the ocular image to the accommodated eye

$$S'_{ok} = -S_n \tag{4}$$

with $S_n = 25\text{cm}$.

Length of microscope tube for accommodated eye

$$d = S'_{ob} + S_{ok} \tag{5}$$

By S'_{ob} is the objective shadow distance calculated by

$$S'_{ob} = \frac{h'_{ob}}{h_{ob}} = \frac{-S'_{ob}}{S_{ob}} \tag{6}$$

and S_{ok} is the ocular object distance calculated by

$$S_{ok} = \frac{S'_{ok} f_{ok}}{S_{ob} - f_{ok}} \tag{7}$$

For the non-accommodating eye, the final image produced by the objective lens should fall exactly on the focal point of the eyepiece. Under these circumstances, the rays refracted by the eyepiece will be parallel rays (Kanginan, 2007). Thus:

$$S_{ok} = f_{ok} \tag{8}$$

Length of microscope tube for non-accommodating eye

$$d = S'_{ob} + f_{ok} \tag{9}$$

Magnification at the eyepiece, M ok for the unaccommodated eye

$$M_{ok} = \frac{S_n}{f_{ok}} \tag{10}$$

4) Binoculars

Binoculars or telescopes are optical devices designed to observe very distant objects, so that they appear closer and clearer. They make it possible to observe celestial bodies such as the moon, planets and stars. Using telescopes, many important space-related discoveries have been made. Telescopes are generally divided into two types: refracting telescopes and reflecting telescopes. The main difference between the two lies in the type of lens or mirror used on the objective. A refractive telescope utilises a lens as an objective, i.e. an objective lens, while a reflecting telescope uses a mirror as an objective. The shadow formation process on a refractive telescope can be seen in Figure 5.a, while the shadow formation on a reflective telescope is shown in Figure 5.b.

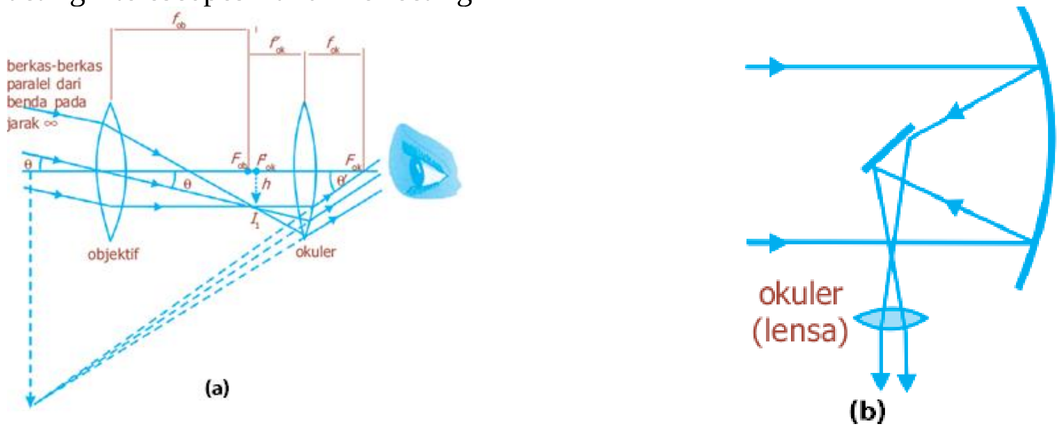


Figure 5. Shadow Formation in (a) Biased Binoculars (b) Reflecting Binoculars (Sumarsono, 2009)

5) Camera

A camera is an optical device that shares similarities with the function of the human eye. There are three basic elements in a camera lens: a convex lens, a slit diaphragm, and a film (or sensitive plate). The convex lens is responsible for forming the shadow of the object being photographed, while the slit diaphragm controls the amount of light entering the camera. Film plays an important role in capturing the image produced by the lens, made of light-sensitive chemicals that react when exposed to light.

In a camera, these three elements can be likened to the parts of an eye: the convex lens acts like an eyepiece, the iris acts as a slit diaphragm that regulates light, and the retina acts like a film that captures images. The way a camera works is quite simple. The object you want to capture must be placed in front of the lens. When the diaphragm is opened, light reflected from the object will enter through the gap in the diaphragm into the lens. The lens then forms a shadow of the visible object. In order for the shadow to be clearly focused on the film, the position of the lens must be adjusted by sliding it closer or further away from the film, similar to the way the eye accommodates to focus the view. A diagram showing the formation of shadows on a camera can be seen in Figure 6.

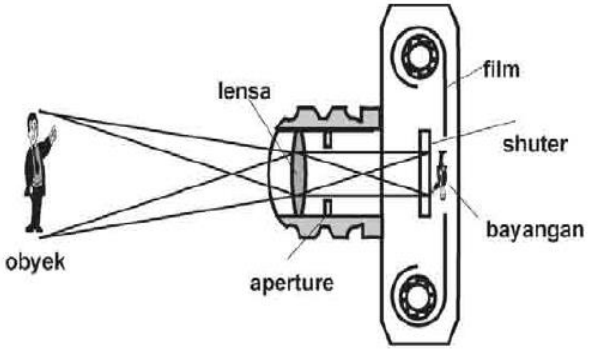


Figure 6. Shadow Formation on a Camera (Karyono, et al 2009)

2. METHOD

In this study, the conceptual experiment method (Teodoro, V. D., 1998) was used to identify physics concepts in geometric optics phenomena in optical devices namely the eye, lup, microscope, binoculars and camera in a measurable and objective manner. The software used is Algodoo 2D Simulation v2.2.0. This software is used as a simulation application to support experiments and run on a 64-bit Windows 10 operating system. The conceptual approach is very useful in this research as it allows in-depth conceptual analysis of the simulations obtained, which provides valid and reliable results. This method is adopted from the methods used by Del Carpio Minaya & Ponce Atencio (2020), Fitrianingrum & Pawarangan (2024) and Coramik & Ürek (2021). This study consisted of three main activities in the experiment of shadow formation on optical instruments (eye, lup, microscope, binoculars and camera). These activities include the steps of:

1. Designing an experiment using Algodoo to model the phenomenon of shadow formation. This design uses schemes/pictures of optical devices that are close to reality so that it is expected to make it easier for students to understand the process of shadow formation.
2. Configuring optical devices, light sources, rays, lenses so as to obtain the appropriate shadow formation. In this step, measurements/findings of position and related variables related to the formation of shadows on optical devices are also carried out.
3. Conceptually analyse the results of simulation and *fitting* with the concept of shadow formation in optical devices. Some students were asked to try out the experimental design with the main objective of finding out whether the experiment could operate conceptually according to the needs of the related physics concepts. These student trials were observed and reported qualitatively. As the main objective was to demonstrate that the experimental design was not confusing to operationalise and was conceptually correct.

3. RESULT AND DISCUSSION

Simulasi pembentukan bayangan yang dibuat with Algodoo must be developed independently according to the concepts and physical phenomena. Algodoo only provides tools related to physical phenomena. The position of objects, incident rays, ray directions, lenses and related optical devices are arranged in such a way as to show how the shadow formation process on these optical devices. Therefore, the design of this shadow formation experiment must really pay attention to physical conceptual analysis.

3.1 Design of the Shadow Formation Experiment of the Eye Optical Apparatus

The eye shadow formation experiment was simulated using a drawing of the eye (not a sketch). The light comes into the eye and the shadow falls inside the eye. Because to show myopia (nearsightedness) and hyperopia (farsightedness), it is designed that the shadow falls incorrectly on the retina. As in the concept of physics, these two eye defects can be overcome with glasses with concave and convex lenses, so concave and convex lenses are provided. Figure 6 shows the process of image formation in the eye when the eye suffers from myopia and hyperopia defects. The lenses needed to overcome these defects are provided at the bottom. The defect categories of myopia and hyperopia have also not been paired so in the experiment, students have to pair them according to the physical concepts.

Figure 6. Experimental design of shadow formation process in eyes with myopia and hyperopia defects

Figure 7 shows the experimental exploration of shadow formation on the eye with the Algodoo simulation. This exploration is done by varying the thickness of the convex lens used as the eyepiece. With the simulation of the optical device of the eye, students can observe where the shadows fall on myopic and hyperopic eyes.

Based on the exploration of the experimental design, students can understand the concept of myopia and hyperopia. In addition, students can also explain the cause of the shadow falling on eye defects that are not right on the retina. After the exploration, students can explain that for eyes with myopia the shadow will fall behind the retina. This is because the lens of the myopic eye is difficult to flatten which is indicated by the shape of the lens of the eye which is much more convex than the hyperopia eye. Therefore, the treatment for myopic eyes is to use concave lenses. Conversely, in hyperopic eyes the shadow will fall behind the retina. This is because the lens of the hyperopia eye is difficult to bulge, which is indicated by the flatter shape of the lens compared to the myopia eye. Therefore, the treatment for hyperopia is to use a convex lens.

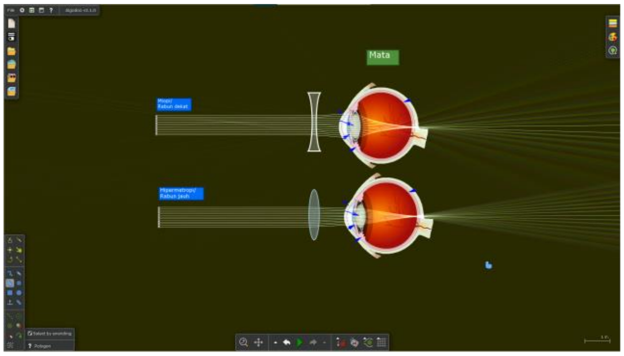


Figure 7. Correct display of experiments on the process of shadow formation in eyes with myopia and hyperopia defects

The simulation of the optical tools of the eye can also help students understand the concept of shadow formation in myopia and hyperopia, the causes and treatments.

3.2 Experimental Design of Shadow Formation of the Lup Optical Apparatus

Exploration of the concept of shadow formation using a lup is done by changing the distance of the object placed in front of the lup to see the difference in shadow formation in the accommodated and unaccommodated eyes. Through the simulation of the optical instrument, students can observe how special rays work in the shadow formation process and determine the characteristics of the resulting shadows. With this approach, students can understand the concept of shadow formation in a lup for both accommodated and unaccommodated eyes. This is reflected in the students' answers after using the simulation, where they explain that for the accommodated eye, the position of the object is right at the focal point, producing an image that is virtual, upright, and magnified. In contrast, for the unaccommodated eye, the object is located closer to the focal point of the lup and does not produce a shadow.

Based on the explanation, it can be concluded that the simulation of the optical instrument of the lup can be operated easily by students. In addition, the simulation can also help students in understanding the concept of shadow formation on the lup for accommodated and non-accommodated eyes.

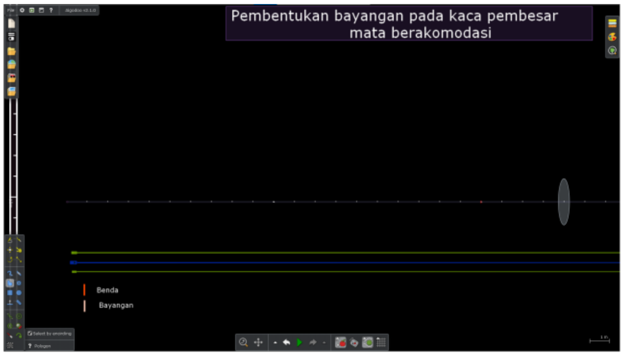
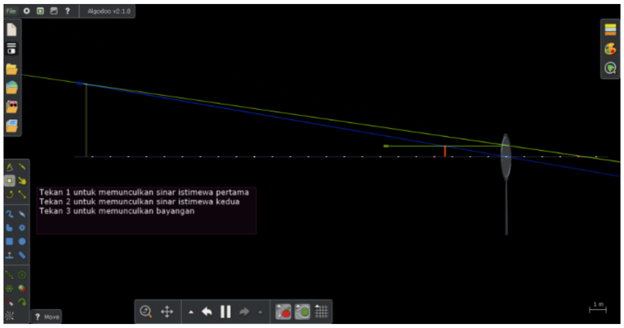

Pembentukan bayangan pada kaca pembesar
mata berakomodasi

Figure 8. Experimental design of shadow formation on a magnifying glass/lup with an accommodated eye



Tekan 1 untuk memunculkan sinar istimewa pertama
Tekan 2 untuk memunculkan sinar istimewa kedua
Tekan 3 untuk memunculkan bayangan

Figure 9. Shadow formation on a magnifying glass/lup with an unaccommodated eye

3.3 Experimental Design of Shadow Formation of Microscope Optical Device

The exploration of the shadow formation experimental design (Figure 10) was carried out to test the correctness of the concept of shadow formation on a microscope, both for accommodated and non-accommodated eyes. In the accommodated eye, the shadow produced by the objective lens is located in front of the focal point of the eyepiece, resulting in an image that is virtual, upright and magnified. Meanwhile, in the unaccommodated eye, the shadow formed by the objective lens is right at the focal point of the eyepiece, so no final shadow is formed on the microscope.

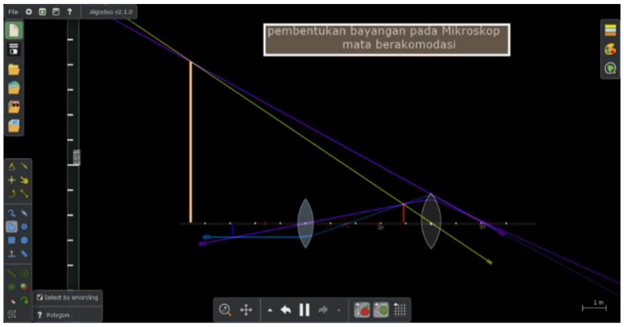


Figure 10. Experimental design of shadow formation on a microscope with an accommodated eye

This concept was then tested through simulation. The test is done by varying the position of the shadow produced by the objective lens, which serves as an object for the ocular lens. By using a microscope simulation, students can observe the path of special rays in the process of forming shadows on the microscope, both for accommodated and unaccommodated eyes. From this observation, students can verify their understanding of the concept and gain a deeper understanding.

3.4 Teleskop Design of Telescope Optical Device Shadow Formation Experiment

Exploration of the experimental design of shadow formation on a telescope, both for accommodated and unaccommodated eyes, was carried out using a simulation of a telescope optical device, as shown in Figure 11.

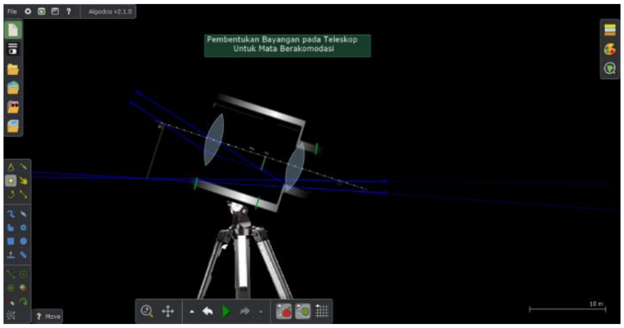


Figure 11. Experimental design of shadow formation on a telescope with an accommodated eye

In this exploration, the position of the shadow produced by the objective lens is varied, which then serves as an object for the eyepiece. With the help of a telescope simulation, students can observe the movement of special rays involved in the shadow formation process on a telescope, both for accommodated and unaccommodated eyes. The results of these observations help students understand more clearly the concept of shadow formation on a telescope. This understanding is reflected in the students' answers after using the simulation. They explained that for the accommodated eye, the shadow produced by the objective lens should be located in front of the focal point of the eyepiece. Meanwhile, for the unaccommodated eye, the shadow produced by the objective lens is right at the focal point between the objective lens and the eyepiece.

In addition, by using a telescope simulation, students also understand that the formation of shadows on a telescope for accommodated eyes produces virtual, inverted, and reduced shadows. Whereas in the unaccommodated eye, no clear shadow is formed; the resulting shadow has the same size as the object, without experiencing magnification.

From the test results of the telescope optical instrument simulation, it can be concluded that this simulation is easy to operate by students. In addition, this simulation is effective in helping students understand the concept of shadow formation on a telescope, both for accommodated and unaccommodated eyes.

3.5 Experimental Design of Shadow Formation of Camera Optical Device

The simulation of the shadow formation process on the camera's optical device is not only easy to use by students, but also effective in helping students understand the working principles of DSLR cameras, both in manual and automatic shadow formation. This is evident from the changes in students' answers before and after using the simulation. Before operating the simulation, students explained the working principle of DSLR cameras in general, namely by focusing the image, enlarging or reducing it, then taking a photo. This answer is still general and does not relate to specific parts of the DSLR camera. The reason is that students do not know the components in the camera and how light rays enter the camera and form shadows of objects. This ignorance is related to the concept of geometric optics which is abstract, because the light that enters and is refracted by the lens cannot be observed directly.

After that, students explored the working principle of DSLR cameras using a simulation of camera optics, as shown in Figure 12. This exploration involved testing the manual and automatic shooting modes. With the help of the camera optics simulation, students can observe the passage of light into the camera in both modes. This observation helps students understand the concept of the working principle of DSLR cameras in both manual and automatic modes. Students' answers after operating the simulation showed that they were able to explain the working principle of a DSLR camera by relating it to the parts of the camera. For manual mode, students explained that the light entering the camera would be refracted by the lens, then collected on a flat mirror, reflected onto a triangular prism, and finally refracted by the prism towards the observer's eyes. Meanwhile, in the automatic mode, light entering the lens will be directly refracted onto the camera screen without passing through the flat mirror or the pentagonal prism.

Based on the results of trials with the simulation of camera optics tools, it can be concluded that this simulation can be operated properly by students. In addition, this simulation also helps students in understanding the working principles of DSLR cameras, both in the process of forming shadows manually and automatically.

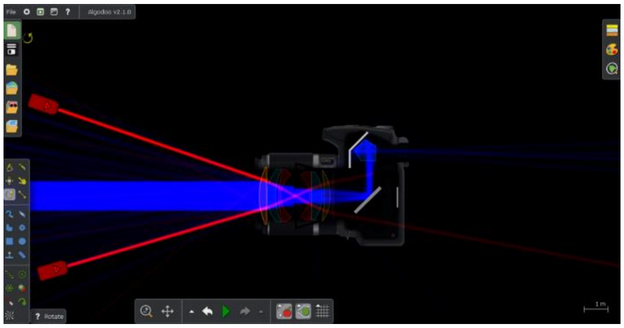


Figure 12. Experimental design of shadow formation on a camera

4. CONCLUSION

The process of shadow formation on the optical instruments of the eye, lup, microscope, telescope and camera can be simulated and experimented using Algodoo 2D simulation software. This shadow formation experiment can be easily understood by students based on observations and students can understand the concept of shadow formation well. This is proven by the fact that students can simulate shadow formation by themselves. Thus, it can be concluded that the 2D Algodoo simulation software can be used to design shadow formation experiments on optical devices well and there are no conceptual errors.

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