Augmented Reality in Science Education as an Innovative Approach via Ray Optics

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***Abstract*—Optics involves understanding light behavior for theoretical and practical advancements. The Ray Optics application allows users to visualize optical phenomena using an interactive virtual optical bench, enhancing conceptual comprehension through real-time manipulation of lenses and light rays. By integrating AR, the study seeks to address challenges in teaching abstract optical concepts, emphasizing the interactivity. Participants in our work were divided into two groups: one used the AR application, while the other relied on traditional methods. Results demonstrated that AR facilitated better understanding of refraction and image formation compared to conventional approaches. Students found the AR-based learning experience more engaging and effective, appreciating its clarity and interactivity. The AR application offers several features: simulations of convex and concave lenses, visualization of light paths, and real-time adjustments of lens parameters. These tools enable users to explore optical principles practically, fostering critical thinking and problem-solving skills. Feedback from participants highlighted AR's potential to transform science education, making complex concepts accessible and promoting active learning. The findings underscore the importance of incorporating technology in physics education. AR not only enhances student interaction but also aligns with contemporary pedagogical trends, paving the way for innovative teaching methods. The study concludes that AR can serve as a valuable resource for both students and educators, enriching the educational process and expanding its applicability beyond optics to other scientific disciplines. In this work, we present an overview of the concepts of optics and the functioning of the Ray Optics application. Furthermore, we emphasize the importance of optics in daily life and how the application can help visualize complex concepts in a practical and interactive way through augmented reality.**

***Keywords*—augmented reality, Ray Optics AR, physics, geometric optics**

I. Introduction

Since ancient times, humans have sought to explain and understand the phenomena present in the world, and physics stands out in this pursuit. Physics is a science that studies natural phenomena, capable of explaining everyday occurrences as well as the functioning of complex systems like light [1].

Optics is dedicated to studying the behavior of light, playing an essential role in advancing science and technology. Understanding optical phenomena is vital not only for theoretical development but also for practical applications across various fields, from teaching science at higher education levels to applied technologies. In the educational context, the effectiveness of optics instruction depends on methods that make abstract concepts more accessible and comprehensible to students [2].

Furthermore, unraveling the principles of this discipline represents a significant challenge for students, as difficulties in teaching optics have persisted over the years. Among the several strategies proposed to facilitate learning in physics, laboratory experimentation stands out as a widely adopted and increasingly effective method [3].

Thus, among the tools used in optics experiments is the optical bench, which supports various activities by enabling precise execution of experiments and the concrete visualization of optical phenomena. Well-designed experimental activities provide an engaging and practical learning environment, encouraging students to explore and better understand the principles of geometric optics using lenses [3].

II. Literature Review

A. Optic

Optics is an essential field of Classical Mechanics that studies the propagation of light, the media through which it travels, the types of emitting sources, and optical phenomena such as reflection, refraction, absorption, dispersion, interference, and diffraction [4]. Despite being a common topic, the behavior of light is notoriously complex, as it is described by both the corpuscular and wave models.

Historically, the corpuscular model of light was widely accepted thanks to the contributions of Isaac Newton in the 19th century [5]. Newton provided simple explanations for phenomena such as reflection and refraction. However, in 1678, Christiaan Huygens proposed a wave model of light, demonstrating that it could be understood as waves obeying the laws of reflection and refraction [6]. This idea, however, faced resistance since waves were understood to

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require a material medium for propagation, while light seemed to travel through a vacuum.

It was not until 1801 that Thomas Young, through his famous double-slit experiment, experimentally confirmed the wave nature of light, highlighting the phenomenon of interference. This milestone consolidated the idea that light waves, when combined, could generate patterns of constructive and destructive interference. Later, in 1865, James Clerk Maxwell unified electromagnetism in his theory, mathematically predicting that light is a form of high-frequency electromagnetic wave. In 1887, Heinrich Hertz experimentally confirmed Maxwell's theory by producing and detecting electromagnetic waves, verifying properties such as reflection and refraction, common to all waves.

In recent years, optics has remained a relevant topic of scientific investigation, including studies on technological and educational applications.

B. Lenses

Light is a type of electromagnetic energy that travels through a vacuum and materials at different speeds. According to wave theory, light is characterized as an electromagnetic wave propagating in a direction opposite to the oscillating electric and magnetic fields. On the other hand, the corpuscular theory describes light as particles identified as photons, which possess energy and momentum, highlighting the need to study and understand optical phenomena [3].

Additionally, education in geometric optics usually focuses on providing an understanding of the fundamentals of this field and how to use them to analyze and solve problems associated with light and image creation [7].

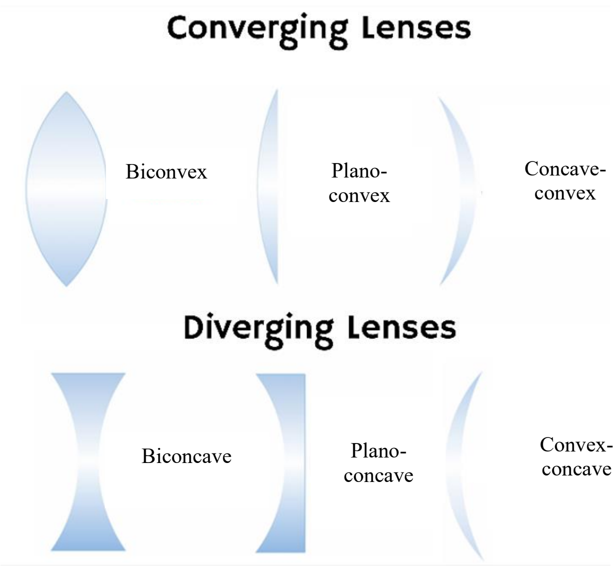

Fig. 1. Types of lenses that can be used on an optical bench.

Lenses, for instance, are optical elements with spherical surfaces that can bend and focus light, forming images of objects. They are widely used in various devices, such as eyeglasses, cameras, microscopes, and telescopes. Lenses can be classified into two main types: converging and diverging, as we can see in Fig. 1. Converging lenses, also known as convex lenses, are thicker at the center than at the edges and focus light rays at a focal point. Diverging lenses, or concave lenses, are thinner at the center and spread out light rays passing through them.

Converging and diverging spherical lenses are used for image formation in various optical applications. Experimental activities in optics education have proven highly effective in helping students understand theoretical concepts. For example, the optical bench allows for precise experiments and the concrete visualization of optical phenomena, facilitating engaging and practical learning experiences that move beyond theoretical content.

This approach aligns with Guidelines and Bases Law [8], which defines the purpose of basic education as developing students for citizenship, ethics, and critical thinking. This underscores the necessity of moving beyond purely theoretical instruction and seeking ways to enhance science teaching with applied physics concepts [9]. Experimental activities help explore the basic principles of geometric optics, engaging students and demystifying the notion that physics is merely a collection of equations [10], thereby promoting a deeper understanding of optical phenomena, especially when integrated with new technologies such as augmented reality.

C. Augmented Reality

Nowadays, we are increasingly immersed in a period of rapid technological innovation that is reaching educational institutions, profoundly transforming how we teach and acquire knowledge. This transformation drives us to abandon conventional practices and adopt new methods.

In addition to traditional methodologies, technological innovation has opened new possibilities for teaching optics. Augmented Reality (AR) emerges as a promising tool capable of transforming how content is presented and interpreted, as technology-mediated learning can lead to greater participation, responsibility, and autonomy among students [11]. By integrating virtual elements into the real environment, AR provides an interactive and immersive learning experience. Studies show that the use of AR in education can significantly enhance student participation and teaching effectiveness, particularly in disciplines involving complex and abstract concepts [2].

One of the main benefits of using AR in education is the increased motivation among students. By incorporating interactive and visual elements, such as 3D models and animations, learning becomes more attractive and interesting for students. Studies have demonstrated that AR can significantly improve students' attention and interest, resulting in more effective learning [12].

Moreover, AR facilitates the visualization of complex concepts, allowing students to interact with phenomena that would otherwise be challenging to comprehend through static texts or images. For example, in disciplines such as science and mathematics, AR can be used to represent experiments, molecular structures, and geometric models, promoting a deeper understanding of the content [2].

In addition, students can conduct virtual simulations and experiments, which is particularly useful in situations where physical experiments are unfeasible due to time, cost, or safety constraints. Through AR, students can explore different scenarios and observe the results of their actions in real time, reinforcing applied and practical learning [12].

In this work, we present an overview of the concepts of optics and the functioning of the Ray Optics application. Furthermore, we emphasize the importance of optics in daily life and how the application can help visualize complex concepts in a practical and interactive way through augmented reality.

III. Materials and Methods

The process began with a brief explanation of the basic concepts of optics, followed by the installation of the application. After downloading the app, from the Play Store, users can access an interactive simulation that allows them to visualize and move objects, observing how the image changes accordingly.

By visualizing the image via augmented reality, users can control the type of lens and focal distance. This means users can switch between convex and concave lenses and adjust the focal length to see how these changes affect image formation.

It is worth noting that during the simulation, users can save their observations via screenshots and observe, in real time, the trajectory of light rays and image formation, identifying whether the image is real, virtual, upright, or inverted.

The Ray Optics AR application is designed for mobile devices and features an intuitive interface with the following key functionalities: (i) introduction to basic topics of reflection, refraction, and lens types, providing users with insights into the properties of convex and concave lenses; (ii) simulation of spherical lenses through object manipulation and image formation observation, allowing adjustments to focal distance and lens type; (iii) demonstration of Gauss's Law; (iv) visualization of image formation using virtual lenses positioned on the screen in augmented reality.

To evaluate the effectiveness of the application as an educational tool, tests were conducted with a group of students enrolled in the Optics Experiments course at our institution, aiming to train them as multipliers of this tool in basic education across our state.

The participants were divided into two groups: Group A used the Ray Optics AR application to review concepts, while Group B used traditional methods, such as lectures and laboratory simulations. At the end of the study, both groups completed a test containing theoretical and practical questions.

The study, utilizing an augmented reality optical bench for teaching optics, produced significant results highlighting the advantages of this tool and its applications in teacher training. To operate the application, students must point their mobile device cameras at Fig. 2.

In addition, the application's representation consists of an optical bench with movable supports, allowing the adjustment of positions and the observation of light beams as they pass through the lens and reach the screen, as shown in Fig. 3.

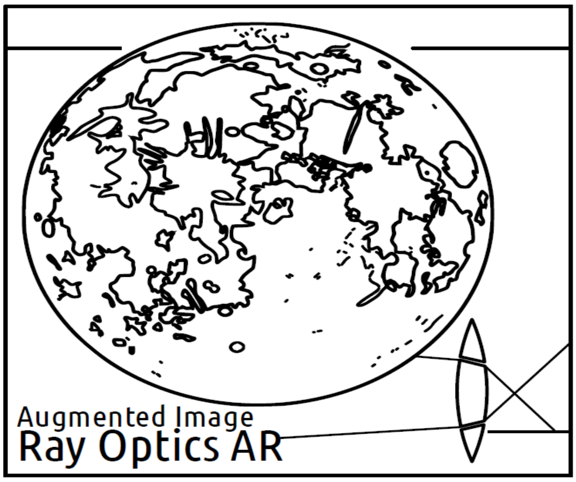

Fig. 2. QR code for generating an augmented reality image of an optical bench.

Fig. 3. Representation of the optical bench created with augmented reality.

IV. Result and Discussion

Students who participated in activities using this tool, as shown in Fig. 4, demonstrated a clearer understanding of concepts such as refraction and image formation by lenses. Observations during the lessons indicated that students could visualize and manipulate optical phenomena more intuitively and interactively, facilitating the assimilation of theoretical content.

The students followed a structured guide to conduct the experiment, which required a smartphone, a spacious table, and a QR code (Augmented Reality Card).

The primary objective was to study optical phenomena through augmented reality. Initially, the experiment involved selecting a radius of curvature for the lens, calculating its focal length, and observing the type of image formed, such as whether it was upright or inverted, real or virtual. Subsequently, the object was positioned 20 cm from the lens vertex.

For a focal length of 10 cm, the image distance was calculated. The experiment continued with the object placed at 15 cm from the focal length, where the students characterized the images formed, determining if they were real or virtual, upright or inverted, and smaller or larger. The object was analyzed at different positions relative to the lens: 40 cm, 25 cm, and 10 cm away. The students recorded the values obtained for object and image distances, ultimately constructing a graph of de 1/p versus 1/p', where p represents the object distance and p' the image distance.

Fig. 4. Students in the optical experiments course using the app.

During the practical activities, students demonstrated notable participation, showing enthusiasm and curiosity in exploring the optical experiments facilitated by augmented reality. Feedback was overwhelmingly positive, with many students expressing that the experience with the AR optical bench was more engaging and interesting than traditional lessons. They particularly appreciated the clarity of visualizations and the ease with which complex optical concepts were understood. The results of the study have been broadly positive, with the primary challenge being the need for a mobile device.

The effectiveness of the AR materials was demonstrated through the analysis of test results applied to the experimental and control groups. The group that used the Ray Optics AR application showed a significantly clearer understanding of refraction and image formation. Additionally, this claim is supported by the differences observed in average scores, which evidenced greater assimilation of concepts by the experimental group due to the interactivity and practical visualization provided by AR.

V. Conclusion

The study of optics is fundamental to understanding many physical phenomena that govern the behavior of light, an important aspect of both everyday experiences and advanced scientific applications. Optics, as a branch of physics, deals with the study of light propagation, interaction with several materials, and the formation of images, offering insights into everything from simple lenses to complex phenomena such as diffraction and interference. Despite its wide application, optics remains a complex field, often perceived as abstract and challenging by students. The mathematical rigor required to understand concepts such as ray tracing, reflection, and refraction can be intimidating, and traditional teaching methods sometimes fail to fully engage students with the material.

However, the integration of innovative technologies, particularly Augmented Reality (AR), is revolutionizing the way optics is taught, making it more accessible and engaging. The use of AR in optics education allows students to visualize and manipulate optical phenomena in real-time, providing an interactive learning experience that bridges the gap between theoretical knowledge and practical application. By superimposing digital images and models onto the physical world, AR enables students to observe the behavior of light as it interacts with objects, such as lenses or mirrors, in a dynamic and hands-on way. This visual and immersive approach enhances understanding by allowing learners to experiment with concepts in a virtual environment, reinforcing their grasp of abstract principles.

This study highlights the importance of experimentation and technological innovation in the teaching of optics, particularly through the use of the Ray Optics AR application. By presenting a tool that enables students to visualize and manipulate optical phenomena, the study demonstrates how interactive technologies can significantly transform the way students engage with content. These technologies foster critical thinking, as students are not only passive recipients of information but active participants in the learning process. Through virtual manipulation, they are encouraged to think analytically and solve problems in a practical context, which helps develop valuable problem-solving skills.

Moreover, the application of AR in teaching optics is not only beneficial for students but also serves as an effective tool for teacher training. Educators can use such technologies to explore new pedagogical approaches and develop more dynamic and accessible teaching methodologies. This shift towards technology-enhanced learning aligns with the growing demand for teaching strategies that cater to diverse learning styles and abilities, making education more inclusive.

The use of augmented reality in optics education has thus proven to be an effective strategy for enriching the educational process. It transforms the traditional learning environment by creating an interactive, engaging, and visual space where students can explore complex concepts at their own pace. By aligning the learning experience with contemporary technological trends, AR fosters a more inclusive, modern, and student-centered educational approach. Future research could explore how such technology could be expanded to other areas of physics, evaluating its long-term impact on students' understanding and retention of complex scientific concepts. This shift not only enhances students' learning experiences but also aligns with the evolving demands of the digital age, where technological fluency is becoming increasingly essential.

Based on the collected data, we can conclude that while the experimental group, which used the Ray Optics AR application, achieved an average of 25% higher accuracy in the optical concepts test, the control group remained limited to the performance of traditional approaches. The data analysis suggests that AR facilitates learning by integrating interactivity and real-time visualization, promoting a deeper and more immediate understanding of the concepts.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Welberth S. Ferreira wrote the paper and conducted the research; Iury T. D. Botelho combed the literature and Suelen R. B. Ferreira revised the manuscript; all authors had approved the final version.

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