An Innovative Teaching Method for Geometric Optics Using Hands-On Exercises in a Large Classroom Setting to Stimulate Engaged Learning

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Abstract

Conceptualizing the principles taught in geometric optics is difficult for many optometry students. A novel teaching method was developed to address this challenge. Hands-on activities utilizing refractive lenses, mirrors and light sources not only allow learners to visualize the concepts being taught in class but also sustain their interest and attention and result in more engaged learning.

Key Words: *geometric optics, engaged learning, visualization, hands-on activities, higher education*

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Introduction

The creation of the National Survey of Student Engagement (NSSE) has elicited curiosity and interest among educators in higher learning regarding their students' engagement in the classroom.[1,2] Schreiner and Louis have defined engaged learning as positive energy invested in one's own learning, evidenced by meaningful processing, attention to what is happening at the moment and involvement in specific learning activities.[3]

For instructors in the geometric optics series taught in first-year optometry curricula, a primary goal is to stimulate the highest level of student engagement in the classroom and motivate students for deeper learning in a decidedly demanding curriculum. Traditional lecturing can be ineffective in stimulating student engagement. Moreover, it leaves the visualization of important principles to a student's imagination, leaving many with an incomplete grasp of the challenging concepts taught in the course. With the growing emphasis of our profession on conceptual understanding, deeper learning and comprehension are expected of our students, and there is a resulting need to de-emphasize rote memorization of formulae with "plug-and-chug" calculations.

This paper describes a novel teaching approach that allows hands-on learning of optical principles by small groups of students within the large lecture setting. This method was developed in an effort to increase students' engagement in the classroom and allow visualization of optical principles utilizing table-top equipment. Equipment sets consisting of lenses, mirrors, prisms and laser sources were used in different exercises with the intention of supplementing all major topics taught in the geometric optics course series. In the absence of a laboratory for geometric optics at our institution, these hand-on exercises proved to be an invaluable addition to the course.

Workshops

Over the course of two academic quarters, seven workshop sessions were conducted, with each session scheduled at the completion of the traditional lecture component for a major topic.

During these two-hour sessions, the class of 160 students was divided into 20 groups. Ten groups met during the first hour in the lecture center, and the remaining 10 groups met during the second hour. The group assignments were randomly changed to allow students to work with different colleagues. Each group of eight students worked through some hands-on exercises utilizing laser boxes, lenses and mirrors that were designed to present visually the important concepts already presented during lectures. The students were responsible for setting up the optical equipment based on the instructions in their handout, taking measurements, answering multiple-choice questions, and drawing and labeling ray diagrams. One completed handout was turned in by each group, the correctness of which determined the grade earned for the workshop session by each group member. The discussion questions that followed each exercise were specifically written to ensure that students attended to the crucial elements of the exercise setup and engaged in effective group discussions.

Each group activity and interactive discussion was led by an upper classman teaching assistant (TA) to ensure adequate and effective supervision. Prior to each workshop, a one-hour training session was scheduled for the TAs to ensure consistency in their instructions and a clear understanding of the goals and expectations for the workshop sessions. During these sessions, the TAs performed the entire set of exercises that would later be completed by the first-year students. The training sessions allowed the TAs to review the material, ask questions, and gain confidence for leading the activities and discussions. The TAs were equipped with a written answer key to ensure they provided consistent and accurate answers to their first-year student groups during the workshop sessions. Additionally, the TAs were instructed to make a conscious effort to ensure that each student in their group took the lead role in setting up a minimum of one exercise during the session, participated in all the discussions, and contributed to the group activity. During the workshop sessions, the course coordinator observed and supervised all the groups.

The workshop design aimed to impact deeper learning via fact recall, critical-thinking skills, problem-solving, and enjoyment of the learning activity. The exercise questions were designed to be stepping stones toward the more complex exam questions. The purpose of the exercise questions was to prompt the students to start thinking about and discussing concepts that would later be tested in the exams.

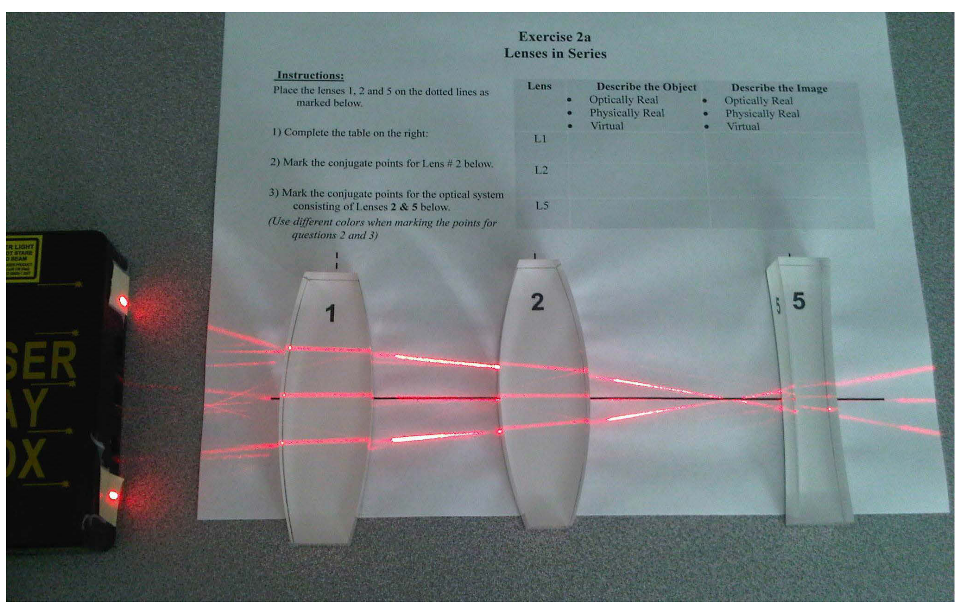
The course was assessed by means of the standard student opinion survey used by the college at the end of each course. The survey did not ask specific questions regarding the workshops. However, unsolicited comments from students and TAs provided useful feedback.

Sample Workshop Exercises

The two exercises described here are among many that were designed to allow the study of optical systems and behavior of light. The first setup **(Figure 1a)**, which utilizes a laser light source, two convergent lenses and one divergent lens arranged in series, facilitates visualization of real and virtual objects and images. Parallel light rays from the laser box are incident on the first lens (L_1). Convergent rays exit L_1 and are incident on the second convergent lens (L_2). The blue dot in **Figure 1b** marks the location where these convergent rays would have intersected with the optic axis if no other lens had intercepted the light rays. In addition to representing the location of the optically real image for L_1, the blue dot marks the location of the virtual object for L_2. In other words, when convergent light rays exit a lens, they represent a real image. However, when the convergent rays are incident on a lens, they represent a virtual object. Next, the light rays pass through L_2, which

Figure 1a

A setup utilizing two convergent lenses and one divergent lens arranged in series allows students to observe a variety of objects and images. Parallel light rays from the laser box are converged by the first lens (L_1). Before L_1 can form a physically real image, the second convergent lens (L_2) intercepts the rays and converges them even more. The convergent rays that exit L_1 represent the optically real image for L_1 and also the virtual object for L_2. The convergent rays that exit L_2 to form a focal point without being intercepted represent the physically real image for L_2. Next, the light rays diverge and continue their travel toward a divergent lens (L_5), last in the series. L_5 adds divergence to its incident light rays and creates a virtual image.



adds more convergence to the already convergent rays. Because the rays that exit L_2 converge to a focal point without being intercepted, the image for L_2 is physically real. Light rays diverge and continue their travel toward a divergent lens (L_5), positioned last in the series. The orange dot in **Figure 1b** represents the location of the image for L_2 and also the real object for L_5. Divergent light rays exit L_5 and form a virtual image. In order to know the exact location of this virtual image, students are instructed to extrapolate the rays that exit L_5. The green dot in **Figure 1b** marks the location where the divergent rays intersect the optic axis after being extrapolated. An optical setup like the one shown in **Figure 1a** not only aids visualization but also provides the framework for more detailed discussions regarding conjugate points and the resulting image parameters such as size, location and orientation.

After setting up the equipment as photographed in **Figure1a**, the students are instructed to identify the type of object and image for each lens, mark the conjugate points for each lens and draw a ray diagram to represent the optical setup, similar to the one shown in **Figure 1b**. Following are some examples of the discussion questions that the students review with their TA upon completion of exercise 1:

1. Are the incident wavefronts for L_2 steeper or flatter than the emergent wavefronts for L_2? To answer this question, students need to recall that the steepness of wavefronts is directly proportional to the vergence. The students are encouraged to sketch the incident and exiting wavefronts on their diagram, as shown in **Figure 1c**, to help them visualize this concept.
2. Do the incident wavefronts become flatter or steeper as they approach L_2? This question, though testing a similar concept as the previous question, is worded differently to place the emphasis on L_1 rather than L_2. Additionally, it challenges students to think about how convergence increases when convergent light travels downstream toward its focal point. To

Figure 1b

A representation of the exercise setup, as drawn by students in the workshop assignment shown in Figure 1a. The blue circle labeled I_1 and O_2 represents the location of the optically real image for L_1 and the virtual object for L_2. The blue dotted rays leading to this location are obtained by extrapolating the exiting rays for L_1. The orange circle labeled I_2 and O_3 marks the location of the physically real image for L_2, which also serves as the physically real object for L_5. The green circle labeled I_3 represents the location of the virtual image for L_5. This location is obtained by extrapolating the divergent rays that exit L_5 (dotted green rays).

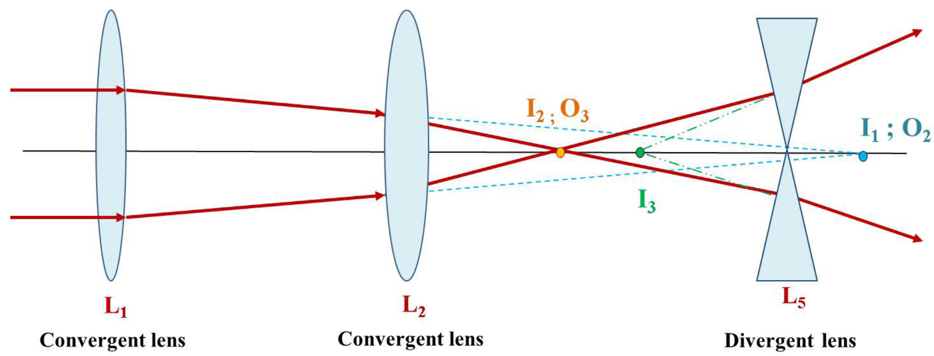
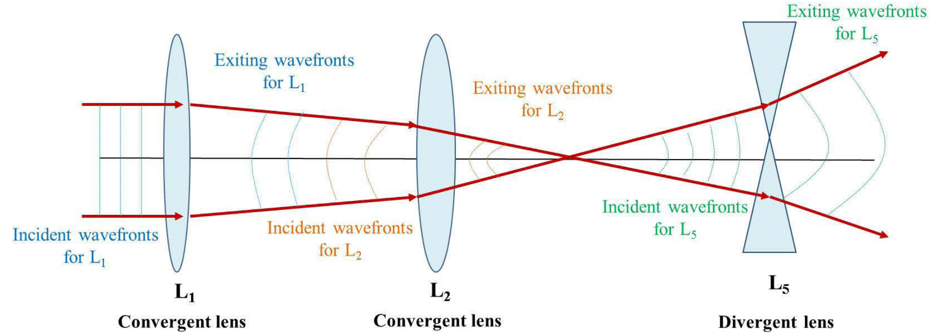


Figure 1c

A diagrammatic representation featuring incident and exiting wavefronts for the exercise setup photographed in Figure 1a. The incident wavefronts for L_1 are flat and perpendicular to the parallel rays originating from infinity. The exiting wavefronts for L_1 are convergent and become steeper as they travel downstream, away from L_1 and approaching their focal point. The exiting wavefronts for L_2 are steeper compared to the incident wavefronts because L_2 adds convergence to the wavefronts. After forming a point focus, the wavefronts that continue to travel downstream toward L_5 are divergent. Divergent wavefronts become weaker and flatter as they travel downstream, away from their point source, and approach L_5. The exiting wavefronts for L_5 are steeper than the incident wavefronts because L_5 adds more divergence to the exiting light rays.



answer this question correctly, the students need to recall that the curvature of wavefronts is inversely proportional to the distance of the wavefront from the focal point.

3. Do the incident wavefronts become flatter or steeper as they approach L_5? This question is designed to initiate a discussion on how divergence decreases as light travels downstream from its point source.

The second exercise, which involves a thick prism and a laser light source, allows students to visualize the passage of a single light ray through a prism. **(Figure 2a)** At the first surface of the prism, the light ray refracts toward the normal as it travels from a rarer to a denser medium. The resulting angle of refraction is smaller than its corresponding incident angle. The light ray then travels through the prism in a straight line to reach the second refracting surface of the prism. At the second surface, the incident angle being larger than the critical angle results in total internal reflection, and the law of reflection governs the behavior of light at this prism surface. The reflected ray creates an incident angle at the third surface (base) of the prism where light travels from a denser to a rarer medium, resulting in a larger angle of refraction than the corresponding incident angle.

The students are instructed to set up the equipment as photographed in **Figure 2a**, measure all angles of incidence, refraction and reflection, draw a ray diagram as shown in **Figure 2b** and label all the angles. Snell's law is applied to aid understanding of the relationship between the incident angle and the angle of refraction at each surface of the prism. Students are asked to calculate the value of the critical angle for the prism and predict which incident angles at the second refracting surface of the prism would yield total internal reflection. This setup also provides the framework for observing the effect of the prism's apical angle and refractive index on the deviation of light by employing different prisms. This workshop provides an effective visual vehicle for observing the set-up for minimum deviation, maximum deviation and normal incidence with thick prisms.

Figure 2a

Utilizing a laser box and thick prism, students can study the relationship between variables, including the angles of incidence and refraction (or reflection) of light, the apical angle of the prism and the index of refraction.

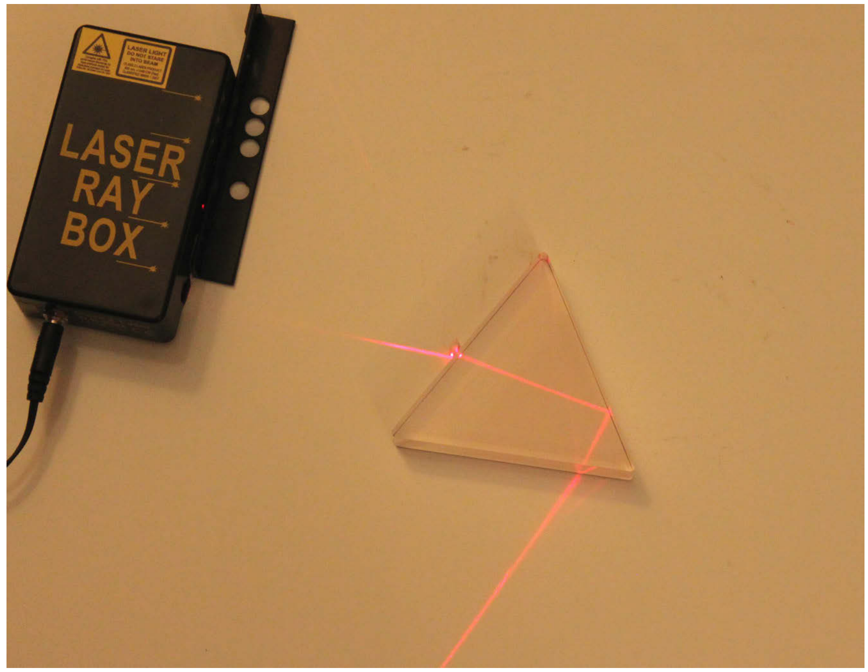
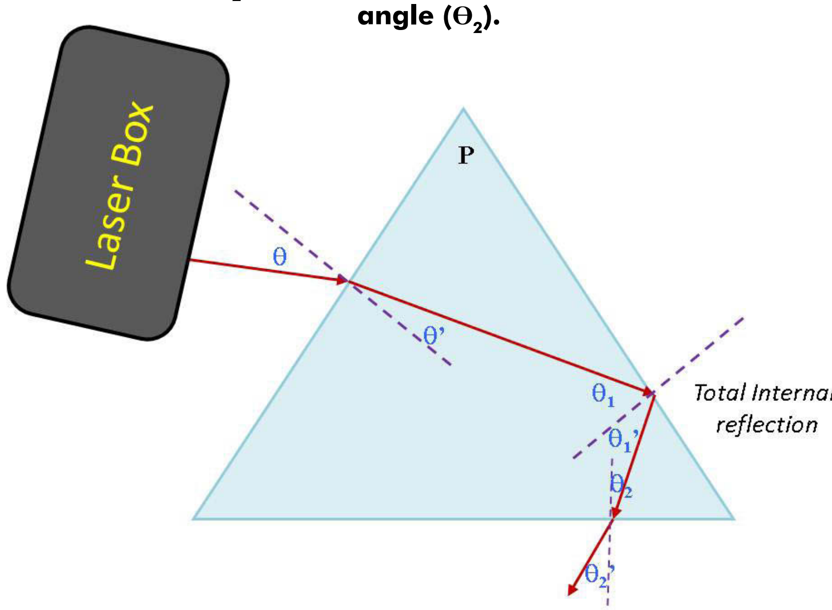


Figure 2b

A diagrammatic representation of the exercise setup, as completed by students in the workshop assignment shown in Figure 2a. Light refracts toward the normal at the first surface of the prism. The resulting angle of refraction (Θ') is smaller than the incident angle (Θ) at the first surface. Light reflects at the second surface because the incident angle (Θ_1) is larger than the critical angle for this prism. The corresponding angle of reflection (Θ_1') is equal to Θ_1. Light refracts away from the normal at the third surface of the prism. The resulting angle of refraction (Θ_2) is greater than the corresponding incident angle (Θ_2).



Impressions

Informal feedback from students and colleagues indicated that the new hands-on activities were well-received by a majority of the students. Students enjoyed the activities and appreciated being able to observe the behavior of light. A majority of the students commented on enjoying the interaction and discussions with their colleagues. Some students stated that they liked the activities due to the variety that they brought to the course and that the activities kept them engaged and interested. Students also commented that discussing a concept with their colleagues helped them understand it better and prompted them to pay attention to details they may have otherwise overlooked. Higher scores were observed on scheduled mid-quarter and final comprehensive examinations compared to the previous year, possibly reflecting better grasp of concepts. Additionally, the exam performance was improved in spite of a larger proportion of conceptual questions that are generally considered to be more challenging by students.

Many uncontrolled variables can potentially influence exam performance from one year to the next, such as the student body itself and changes in class and exam schedules. Therefore, it is inappropriate to attribute improved exam performance solely to the workshops. A more controlled study in the future, with the use of pre-workshop and post-workshop exams, might better allow determination of the impact of these workshops on students' exam performance. Students also commented on ways to improve the activities, which included suggestions for more time to ensure adequate opportunity for discussions with the group TAs. Students requested better timing of the workshops in the weekly schedule to increase the time between the workshops and exams. Both of these issues can be addressed easily going forward.

Clinical instructors who worked with students who had participated in the optics workshops the previous year and rotated through the Low Vision Service in an observational capacity reported a noticeable difference in students' understanding of the underlying optical principles of low vision devices, particularly fixed-focus magnifiers and the resulting virtual image. Positive comments were also received from the TAs, who reported that the concepts covered during these workshop sessions allowed them to better understand the course material compared to when they had learned it themselves originally, without workshops. Upper classmen have requested a workshop session to help them review the course material for the National Board Examination.

Discussion

Several studies have examined and reported the benefits of group collaboration and engagement. The positive correlation between engagement and deeper learning has been reported by Tagg.[4] Benbunan-Fich and Arbaugh found that students on average achieved better grades in courses where they engaged in collaborative assignments and participated in knowledge construction. In terms of final grades, the absence of both factors (knowledge construction and group collaboration) had a detrimental effect on student performance.[5] McHarg et al. reported a positive relationship between students' performance on knowledge-based assessments and the level of group engagement and collaboration in problem-based learning. Students who engaged most during the problem-based learning process performed markedly better in assessments of knowledge.[6]

Carini et al. studied the association between student engagement and academic performance in 1,058 students at 14 four-year colleges and universities. The authors reported a positive link between student engagement and desirable learning outcomes such as critical thinking and grades. The authors also found student engagement to be more beneficial for college students with the lowest SAT scores. Additionally, student engagement was converted into higher performance on critical-thinking tests more effectively at certain institutions than others.[7]

Pollock et al. compared the effects of different types of face-to-face discussions, including small-group and large-class discussions, on learners.[8] Greater participation and more positive student perceptions were reported in small-group discussions. Previous academic achievements were reported to be less impactful on the level of participation in small groups.[8]

The relationship between faculty practices and student engagement has been explored and reported by Umbach and Wawrzynski. Their findings suggest that students report higher levels of engagement and learning at institutions where faculty members use active and collaborative learning techniques, engage students in experiences and activities in the classroom, and maintain a high level of interaction.[9]

Hands-on exercises where the participating student is responsible for setting up the exercise, explaining the setup to his fellow group members and discussing the results guarantee a more active learning approach. These small group exercises require greater student involvement both mentally and physically compared with a large classroom lecture setting where students are allowed to be passive receivers of information.

Inclusion of these hands-on group exercises in this first-year geometric optics course helped the participating students to grasp concepts more easily by means of greater group interaction and presentation of material from a different perspective. A major advantage of group discussions is that they allow the topic of interest to be discussed in multiple ways, with each participant bringing his/her own perspective to the discussion. Additionally, small group activities create a sense of responsibility and accountability among the participants. In these workshops, each group member was required to take the lead role in at least one exercise, which resulted in observable efforts by the participants to better grasp the concepts so they could effectively contribute to the group activity.

Another important feature of these hands-on exercises that makes them uniquely helpful in learning is that they allow visualization. The students are able to actually observe the diverging and converging light rays, pinpoint the exact location and predict the size and orientation of an object or image. With less reliance on their imagination, students can be uniformly equipped with a solid knowledge base. With the basic and trivial concepts mastered, the entire class can then move on to more complex discussions and problem solving. Hands-on activities can play an instrumental role in learning for all students, but likely are especially important for the visual learners.

Currently, a project is under way to examine the link between student engagement during workshop sessions and academic performance. The study will compare students' performance on exam questions before and after participation in workshop sessions by means of short multiple-choice questions. Additionally, the students will be asked to complete a survey to evaluate the contribution of each workshop session to their understanding of the course material.

Conclusion

Courses in higher education, especially those that lack a laboratory portion, can benefit from course components that allow group interaction, activities that trigger engagement and discussion, and exercises that stimulate interest and allow visualization.

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