Journal of Research in Mathematics, Science, and Technology Education
ISSN 3047-5163 (online) & 3047-6933 (print)
April 2025, Vol. 2, No. 1, pp. 46–52

Research Article

Enhancing Student Learning Through Collaborative Inquiry: Determining the Refractive Index of Various Substances

Islom Ruziyev[1], Behruz Sayfullayev[1], Otabek Khushnazarov[1], Akmal Abdimuminov[1], Khadicha Mamatkulova[1]

[1]Presidential School of Qarshi, Qarshi City, Uzbekistan

Abstract
The refractive index is a fundamental property of materials that describes how light propagates through a medium, enabling an understanding of optical phenomena such as refraction. This study investigates the refractive indices of water, oil, and glass using hands-on experimentation based on Snell's Law. The researchers, who were also the participants, conducted the study as part of an independent project under the Cambridge AS Level Physics curriculum. Utilizing basic laboratory materials, including a ray box, protractor, and transparent containers, the experiment involved measuring the angles of incidence and refraction to calculate refractive indices. Each measurement was repeated three times for accuracy, and multiple angles of incidence were tested for consistency. The results showed a strong agreement between experimental and theoretical values, with refractive indices of 1.33 for water, 1.46 for oil, and 1.52 for glass, yielding percent errors of 0%, 0.68%, and 0.66%, respectively. These findings confirmed the reliability of the methodology and the validity of Snell's Law. Minor deviations were attributed to potential sources of error, such as measurement inaccuracies and material impurities. This hands-on activity enhanced the researchers' conceptual understanding of light behavior while promoting critical thinking, problem-solving, and independent research skills. The perspective of the students was meaningful as they enjoyed the activity. The collaborative nature of the activity was an outlet for the participants to enhance their learning. The practical approach fostered a deeper appreciation for experimental physics and demonstrated the importance of systematic data collection and analysis in scientific inquiry. By bridging theory with practice, the study highlighted the value of active learning in understanding complex physical concepts.

Keywords: Collaborative Inquiry, Data Analysis, Independent Study, Physics Education, Snell's Law

Correspondence
Islom Ruziyev
frankpacala@gmail.com

Received
November 25, 2024
Accepted
March 9, 2025
Published
April 7, 2025

Citation: Ruziyev, I., Sayfullayev, B., Khushnazarov, O., Abdimuminov, A., & Mamatkulova, K.. (2025). Enhancing student learning through collaborative inquiry: Determining the refractive index of various substances. *Journal of Research in Mathematics, Science, and Technology Education, 2*(1), 46–52.

DOI: 10.70232/jrmste.v2i1.27

1. INTRODUCTION

The refractive index is a physical property used to describe the propagation behavior of light in a medium. This property allows us to quantify how light is bent or refracted when it passes from one medium into a second medium with a different optical density (Serway & Jewett, 2018). The refractive index n is expressed mathematically as the ratio of the vacuum speed of light c and the light speed in the medium v:

$$n = \frac{c}{v} \qquad \text{(Equation 1)}$$

It is an important characteristic or property in the study of optics, how light behaves through lenses, prisms, and the like. Following Snell's Law, the extent of light refraction can be determined by the angles of incidence θ_1 and the angle of refraction θ_2, as well as the relative indices of the two media (Halliday et al., 2014).

$$n_1\sin(\theta_1) = n_2\sin(\theta_2) \qquad \text{(Equation 2)}$$

In this manner, Shear's Law can be inverted to provide one measure for a medium's relative index of refraction. The medium can be water, glass, oil, or other substances such as air (Tipler & Mosca, 2007).

This experiment's primary objective is to determine the refractive indices of various substances, including water, glass, and oil, by analyzing how light bends as it transitions from air into these materials. The investigation also aims to explore the relationship between the substances' optical properties and their refractive indices.

The standard refractive indices for common materials are well-established in physics, with values such as 1.33 for water and approximately 1.52 for glass (Young & Freedman, 2016). This experiment seeks to verify these values within experimental limits while accounting for potential sources of error, including measurement inaccuracies, light scattering, and surface irregularities. Through careful data collection and analysis, the study aims to demonstrate a systematic approach to determining refractive indices and the challenges associated with experimental methods in optics.

The refractive index is a fundamental property of materials that describes how light propagates through a substance. It is crucial in understanding optical phenomena and has applications in physics, engineering, and material science. In this independent study, students explore the refractive index of various substances through hands-on experimentation. (Hecht, 2017; Richardson & Wiltshire, 2017). This activity emphasizes the development of critical thinking, problem-solving, and practical skills as students independently design and implement methods to measure the refractive index. The study enhances students' conceptual understanding of light behavior and fosters a deeper appreciation of experimental physics, promoting self-directed learning and curiosity in exploring the physical world (Pacala, 2024).

Physics education emphasizes hands-on learning to enhance students' conceptual understanding of complex phenomena such as light behavior. Previous research highlights the importance of practical experimentation in promoting critical thinking and problem-solving skills (Hecht, 2017). However, there is a gap in research regarding how independent experiments, such as determining refractive indices, foster self-directed learning and deepen students' engagement with experimental physics. This study aims to bridge this gap by allowing students to design and conduct experiments to measure various substances' refractive index. By doing so, students will better understand optical properties while developing practical skills and fostering curiosity about the physical world.

In physics education, the ability to independently engage in scientific inquiry is crucial for fostering lifelong learning and scientific literacy (Storksdieck, 2016). This study contributes to the literature by demonstrating how self-directed experimentation in determining refractive indices can enhance both conceptual understanding and research skills, addressing gaps in existing educational approaches to teaching physics. Through this hands-on study, students verify known values of refractive indices and refine their understanding of the scientific process, including the challenges of experimental physics.

This study aims to enable students to determine the refractive index of various substances through self-directed experimentation. Thus, students will enhance their understanding of light propagation and optical properties while fostering critical thinking, problem-solving, and independent research skills.

2. METHODS

2.1. Materials

Table 1 shows the materials used in this experiment. These materials are widely available in standard classroom laboratories, ensuring that the experiment is both practical and accessible to most students. The simplicity of the experimental setup minimizes technical challenges and allows for straightforward measurements.

A set of essential materials and equipment was used to determine the refractive index of various substances, each serving a specific purpose in the experimental setup. A ray box or laser was used to produce a narrow, focused beam of light, enabling precise observation of light's behavior as it passed through different substances. The researcher utilized this equipment to ensure the light beam was directed accurately onto the test material.

Table 1. The List of Materials in This Independent Study

Material/Equipment	Function
Ray box or laser	To produce a narrow and focused beam of light.
Protractor	To measure angles of incidence and refraction.
Transparent block	To test refraction in solid materials like glass.
Transparent container	To hold liquids such as water or oil.
Ruler	To ensure accurate alignment of the setup.
White paper and pencil	To trace light paths and record measurements.

A protractor was employed to measure the angles of incidence and refraction, which were critical for calculating the refractive index. The researcher carefully recorded these angles to ensure precision in the computations. Transparent blocks, such as those made of glass, were used to study the refraction of light in solid materials. In contrast, a transparent container was used to hold liquids like water or oil for similar investigations in fluid media. The researcher selected these materials to compare and analyze how light behaved in different mediums.

A ruler ensured proper alignment and consistency in the setup, reducing experimental errors. The researcher relied on the ruler to maintain accurate spacing and alignment throughout the experiment. White paper and a pencil were utilized to trace the path of the light beam and to record measurements, providing a visual representation and documentation of the refraction process.

2.2. Participants

This study was conducted by three high school students in School A of Uzbekistan. The age of the participants is 16 years old. We are students of AS Level Physics under the 9702 Cambridge curricula. Our teachers supervised the experiment.

2.3. Procedures

The experiment, conducted by a one group of three students from November 15 to 17, 2024, followed a structured timeline. On Day 1, the setup was prepared, and materials were aligned with a ruler to ensure consistency and reduce errors. The light source was adjusted for a focused beam, and preliminary tests with water were conducted to confirm accurate tracing and measurements. Day 2 focused on data collection, where angles of incidence (20°, 30°, 40°) and refraction were measured for water, oil, and glass, with each measurement repeated three times for accuracy in a dimly lit room. On Day 3, the remaining measurements and retests were completed, data was organized, and refractive indices were calculated using Snell's Law, with results verified against expected values. This approach ensured reliable and precise results.

In this experiment, the independent variable is the type of material used (e.g., water, oil, and glass), while the dependent variable is each material's refractive index (n). The refractive index was determined by observing the bending of a narrow light ray as it transitioned between air and the test substance. This approach ensures the precise measurement of angles and consistent application of Snell's Law.

The light source (a ray box or laser pointer) produced a focused and narrow beam of light directed at a fixed angle of incidence (θ_1) toward the material being tested. The refracted ray exiting the material was then carefully traced and measured. For accurate data collection, a protractor was employed to measure the angle of incidence (θ_1) and the angle of refraction (θ_2).

Each measurement was repeated three times for each material to eliminate potential human errors and improve precision. For solid materials, such as glass, the light ray was directed through a block with smooth and uniform surfaces. For liquids, such as water and oil, a transparent container held the liquid, ensuring the light passed through only one refractive surface. This setup minimized errors caused by light scattering or surface irregularities.

Multiple angles of incidence (e.g., 20°, 30°, and 40°) were tested for each material to verify consistency in the refractive index values. The experiment also accounted for potential environmental factors, such as variations in ambient light, by conducting the measurements in a dimly lit room to improve the visibility of the light paths.

This experiment provided reliable data to calculate each substance's refractive index by systematically varying the materials and repeating the measurements. The methodology also considered common sources of error, including human inaccuracies in measuring angles, imperfections in the experimental setup, and environmental disturbances.

3. RESULTS

The experimental results for determining the refractive index of various materials were highly consistent with their theoretical values, indicating the reliability of the methodology used in the study. The experimental gradient (n) for water was exactly 1.33, matching the theoretical value, resulting in a percent error of 0%. This demonstrates a perfect agreement between the experimental data and the expected value, highlighting the precision in measurement and minimal influence of systematic or random errors for this substance.

Table 2. Summary of Data Gathered

Material	Gradient (n)	Theoretical Value	Percent Error
Water	1.33	1.33	0%
Oil	1.46	1.47	0.68%
Glass	1.52	1.51	0.66%

The experimental refractive index for oil was 1.46, compared to the theoretical value of 1.47. The resulting percent error was 0.68%, a minimal deviation, suggesting that the experiment was conducted accurately. Slight differences could be attributed to variations in the specific oil composition compared to the reference value. For glass, the experimental gradient was 1.52, while the theoretical value was 1.51, leading to a percent error of 0.66%. This close agreement reflects the effectiveness of the experimental setup in capturing the refractive properties of solid materials, with minor discrepancies possibly due to the type of glass tested or measurement limitations.

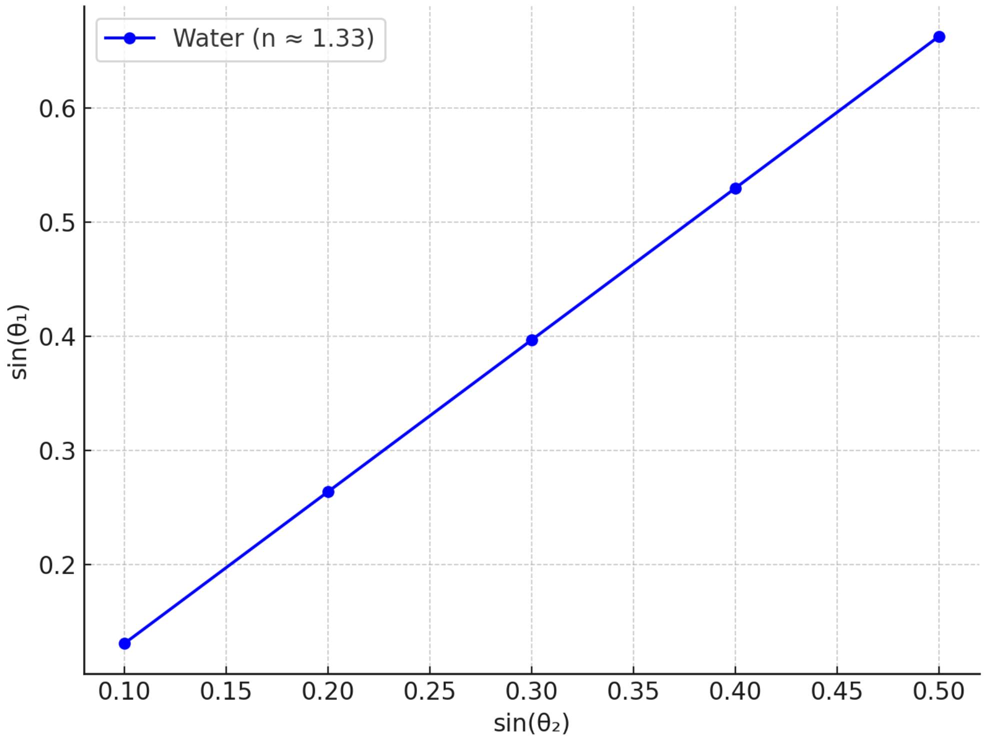

Figure 1. Graph of $\sin(\theta_1)$ and $\sin(\theta_2)$ for Determining the Refractive Index of Water

The relationship between $\sin(\theta_1)$ (sine of the angle of incidence) and $\sin(\theta_2)$ (sine of the angle of refraction) for the tested materials was analyzed using Snell's Law, which is given by Equation 1. To verify this relationship experimentally, a graph of $\sin(\theta_1)$ (y-axis) versus $\sin(\theta_2)$ (x-axis) was plotted for each material. According to Snell's Law, the slope of the best-fit line for this graph represents the material's refractive index (n).

The graph in Figure 1 shows the linear relationship between $\sin(\theta_1)$ and $\sin(\theta_2)$ for water. The graph showed where the data points form a linear trend, confirming Snell's law of refraction. The slope of the line, approximately equal to 1.33, represents the refractive index of water, aligning well with the theoretical value. This consistency highlights the accuracy of the experimental measurements and supports the method's reliability.

The student researchers were overjoyed when the data collaborated with the theory. One groupmate said, "*It was fascinating to see how theory and practice are integrated into this project*." Another student was thrilled to recognize that his achievement increased after the formative test. He claimed, "*I increased my score after conducting this experiment*." Moreover, the students' interest in studying physics was enhanced. A groupmate said, "*My interest in studying physics has become better. I want to explore the natural world more*."

4. DISCUSSION

The results demonstrate a strong agreement between the experimental refractive index values and their theoretical counterparts, confirming the validity of Snell's Law. Minor deviations can be attributed to measurement errors, such as inaccuracies in reading angles with the protractor and material properties, including impurities in oil or irregularities in the glass block that may have slightly altered the refractive indices. Halliday & Freedman (2014) also noted that light scattering caused by surface imperfections or environmental factors might have introduced slight deviations in the light path. Despite these minor sources of error, Park et al. (2013) and Pacala (2023) said that the linearity of the graph and the close alignment of experimental and theoretical values highlight the effectiveness of this method in accurately determining the refractive index of materials.

The researchers, who were also participants in the activity, reported enjoying the hands-on nature of the experiment, as it allowed them to engage directly with the principles of light refraction. By actively measuring angles, setting up the materials, and observing the light's behavior, the researchers found that the activity helped them better understand and connect theoretical concepts to practical applications. Anwer (2019) argued that teachers must adapt to the evolving needs of the classroom and students to ensure that learners find the course engaging and can set meaningful goals. Bogusevschi et al. (2020) support this idea and claim that the more students enjoy the task, the better their learning outcomes will be. Furtak et al. (2019) and Pacala & Pili (2023) argued that the hands-on learning experience facilitated a deeper comprehension of the underlying physics while encouraging problem-solving skills as the participants encountered challenges like ensuring precise measurements and interpreting their data.

The activity provided a valuable opportunity for the researchers to take ownership of their learning, enhancing their enjoyment and understanding of the scientific process. According to the study of Schnaubert and Bodemer (2019), collaboration can improve the students' metacognitive process by allowing them to reflect on their understanding while gaining insights from their peers' perspectives. In addition to enjoying the tasks, students collaborated, following the social constructivism principles emphasizing learning through interaction and shared experiences.

Finally, the student's interest in physics relates to how the activities are connected to real life and how they can solve problems hands-on. This student's experience was relevant in this manner. According to Dahlan and Wibisono (2021), grasping the concept is a crucial foundation for reasoning and solving mathematical problems and real-life challenges. It was also found that the quality of hands-on experiences positively correlated with students' interest in physics activities (Hirca, 2013; Reyes et al., 2024).

5. CONCLUSION

This experiment aimed to determine the refractive index (n) of various materials using Snell's Law and assess the accuracy of the experimental results against theoretical values. Based on the collected data, a robust linear relationship was observed between sin(θ1) and sin(θ1), aligning with Snell's Law's theoretical expectations. The calculated refractive indices for water (n ≈1.33), oil (n ≈1.46), and glass (n ≈ 1.52) are in close agreement with their accepted values, showing only minor deviations.

The slight differences between the experimental and theoretical values are likely due to measurement inaccuracies, such as human error in angle readings, material impurities, or slight light scattering during refraction. Despite these challenges, the results validate the practical application of Snell's Law and demonstrate the reliability of the experimental setup for determining refractive indices. This experiment underscores the importance of careful measurements and controlled conditions when performing optical experiments. The findings confirm the theoretical principles of light refraction and highlight the relationship between incident and refracted angles, contributing to a deeper understanding of the refractive properties of different materials.

In conclusion, the activity provided a practical and engaging way for the researchers, who were also participants, to explore the principles of light refraction. Active involvement in the experiment, from setup to data interpretation, deepened their hands-on understanding of the concepts. This engagement reinforced theoretical knowledge and improved problem-solving and critical thinking skills. Additionally, the collaborative nature of the task fostered increased interest and enjoyment as participants worked together, shared ideas, and solved problems. This experience highlighted the value of teamwork and active inquiry, enhancing conceptual understanding and practical skills in experimental physics.

The implications of this study suggest that hands-on, collaborative experiments can enhance students' understanding of complex physics concepts like light refraction while promoting critical thinking and problem-solving skills. Future studies could explore how different collaboration models impact learning outcomes in physics, particularly in independent experiments. Additionally, further research could investigate the long-term benefits of self-directed inquiry and its role in fostering scientific curiosity and lifelong learning.

Acknowledgment. We want to thank our physics teacher, Mr. Frank, for editing this paper. We also want to thank the Presidential School of Qarshi administration for letting us conduct this study in the school.

Research Ethics. This study followed applicable laws and institutional regulations governing research involving human participants. Ethical approval was obtained on September 12, 2024, with reference number QA29011 from the Office of the Research and Productivity of the school before the commencement of the study. All participants, who were also the researchers, voluntarily participated in the experiment as part of an independent project under our Physics subject. Informed consent was obtained from all participants, and measures were taken to ensure data collection and analysis's integrity, accuracy, and ethical conduct. No personal or sensitive data were collected, and the study posed minimal risk to participants. Any potential sources of bias or conflict of interest were disclosed and addressed accordingly.

Data Availability Statement. The data supporting the findings of this study are available upon reasonable request from the corresponding author. All relevant measurements, calculations, and experimental results have been documented and stored securely. Due to the nature of the study, no personally identifiable information was collected.

Conflicts of Interest. The authors declare that they have no known financial or non-financial conflicts of interest that could have influenced the research reported in this manuscript.

Funding. The study was conducted independently as part of an academic project, with no external funding or commercial affiliations that could introduce bias in the findings.

REFERENCES

Anwer, F. (2019). Activity-based teaching, student motivation and academic achievement. *Journal of Education and Educational Development*, *6*(1), 154-170.

Bogusevschi, D., Muntean, C., & Muntean, G. M. (2020). Teaching and learning physics using 3D virtual learning environment: A case study of combined virtual reality and virtual laboratory in secondary school. *Journal of Computers in Mathematics and Science Teaching*, *39*(1), 5-18.

Furtak, E. M., & Penuel, W. R. (2019). Coming to terms: Addressing the persistence of "hands‐on" and other reform terminology in the era of science as practice. *Science education*, *103*(1), 167-186.

Halliday, D., Resnick, R., & Walker, J. (2014). *Fundamentals of physics* (10th ed.). Wiley.

Hecht, E. (2017). *Optics* (5th ed.). Pearson Education.

Hirça, N. (2013). The Influence of Hands on Physics Experiments on Scientific Process Skills According to Prospective Teachers' Experiences. *European Journal of Physics Education*, *4*(1), 1-9.

Pacala, F. A. (2023). Simple Harmonic Oscillation using Computer Simulation: Compilation of Experiments for Classroom Investigations. *EDUCATUM Journal of Science, Mathematics and Technology*, *10*(1), 80-89.

Pacala, F. A. (2024). Using 5e Instructional Model with ICT Support in Teaching Lower Secondary Students on the Topic of Light Reflection. *Information Technologies and Learning Tools*, *102*(4), 51.

Pacala, F. A., & Pili, U. (2023). Tracking the Acceleration Due to Gravity and Damping of a Pendulum: A Video Analysis. *Physics Education Research Journal*, *5*(2), 83-90.

Park, D. J., Hong, J. T., Park, J. K., Choi, S. B., Son, B. H., Rotermund, F., ... & Ahn, Y. H. (2013). Resonant transmission of terahertz waves through metallic slot antennas on various dielectric substrates. *Current Applied Physics*, *13*(4), 753-757.

Richardson, M. J., & Wiltshire, J. D. (2017). *The hologram: principles and techniques*. John Wiley & Sons.

Reyes, R., Pacala, F. A. A., Bengua, G., & Entac, E. (2024). The Correlation between Students' Insights and Academic Achievement in Science: A Predictor for STEM Career Path. *Formatif: Jurnal Ilmiah Pendidikan MIPA*, *14*(1).

Schnaubert, L., & Bodemer, D. (2019). Providing different types of group awareness information to guide collaborative learning. *International Journal of Computer-Supported Collaborative Learning*, *14*, 7-51.

Serway, R. A., & Jewett, J. W. (2018). *Physics for scientists and engineers* (10th ed.). Cengage Learning.

Storksdieck, M. (2016). Critical information literacy as core skill for lifelong STEM learning in the 21st century: reflections on the desirability and feasibility for widespread science media education. *Cultural studies of science education*, *11*(1), 167-182.

Tipler, P. A., & Mosca, G. (2007). *Physics for scientists and engineers*. W. H. Freeman.

Young, H. D., & Freedman, R. A. (2016). *University physics with modern physics* (14th ed.). Pearson.