Available online at: http://journal.uny.ac.id/index.php/jpms

**Jurnal Pendidikan Matematika dan Sains, 13 (Special Issue), 2025, 260–272**

# REFECTO: GeoGebra-based Interactive Media for Light Waves Topic

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***Abstract***

*REFECTO (Recognizing Fundamental Concepts Through Optics) is a GeoGebra-based instructional simulation developed to help students visually understand wave optics concepts, overcoming laboratory limitations while enhancing conceptual mastery and learning outcomes. An R&D framework, employing the 4D model (Define, Design, Develop) across three iterative phases. The Define phase identified pedagogical gaps through literature synthesis and stakeholder interviews. The Design phase integrated multimodal components aligned with learning needs. The Develop phase involved formative validation by five interdisciplinary experts, followed by phased trials with 31 Grade XI students and three physics teachers at SMA FI Jakarta. Data collection combined expert validation metrics and summative assessments. Rigorous analysis included Aiken's validity index, Cronbach's alpha reliability using a Likert scale response to measure feasibility and practicality, effectiveness was evaluated using a one-group pretest-posttest design, with data analyzed using n-Gain and Cohen's d statistics via SPSS. REFECTO demonstrated robust (validity = 0.92; reliability = 0.76). Field testing showed high practicality based on student responses (validity = 0.90; reliability = 0.65) and teacher responses (validity = 0.85; reliability = 0.60), and statistically significant learning gains, with an N-Gain score of 84% (g = 0.84) and large effect size (d = 4.32). This study successfully operationalizes GeoGebra as a transformative tool for physics education, producing REFECTO a validated, scalable resource addressing critical infrastructure limitations in optics instruction. These findings underscore the potential of open-source platforms to bridge pedagogical divides, while supporting active learning as a strategy to improve student learning outcomes.*

***Keywords:*** *Geogebra, Light waves, Physics learning, REFECTO, Simulation*

**How to Cite**: Aprilia, N., & Romadhon, D. R. (2025). Refecto: Geogebra-based interactive media for light waves topic. *Jurnal Pendidikan Matematika dan Sains, 13*(Special Issue), 260–272. https://doi.org/10.21831/jpms.v13iSpecial_issue.89850

***Permalink/DOI***: ***DOI:*** https://doi.org/10.21831/jpms.v13iSpecial_issue.89850

## INTRODUCTION

The United Nations set the Sustainable Development Goals (SDGs) in 2015 with the intention of promoting national development, and one of the most important components of reaching these goals is education. According to (Mellyzar et al., 2025), one of the 17 primary SDG aims is quality education. The main issue facing Indonesia's educational system is creating a framework that can accommodate the country's steadily expanding student body while also speeding up instruction without sacrificing quality. The goal of this work is to raise a generation that is morally anchored, resilient, and intelligent (Pratama et al., 2025). Despite the implementation of many legislation, field practices suggest that issues in the education sector remain unresolved. The scarcity of educational materials that may connect abstract physics ideas with tangible learning experiences is a problem that often arises (Humairoh et al., 2025).

Physics education frequently encounters challenges in practical instruction, particularly concerning light wave phenomena (Wan et al., 2019; Rohmanasari & Ermawati, 2020). Mastery of light waves is foundational for understanding advanced optical concepts (Szostak, 2011; Cvenić et al., 2021), yet persistent conceptual difficulties often lead to significant misconceptions among students (Mešić et al., 2019); (Hasnain et al., 2010). Conventional pedagogy, reliant on lectures and textbooks, proves insufficient for visualizing complex optical principles, limiting conceptual depth (Carli et al., 2020).

The reasons for conducting the research physics and optics are based on empirical evidence further substantiates these challenges, with optics ranking one of the most difficult physics topics for learners with percentage 25% (Azizah et al., 2015). Effective optics instruction necessitates hands-on visualization, yet inadequate laboratory facilities present critical barriers. Research indicates 82% of Indonesian schools lack essential optical practicum equipment (Dewi et al., 2023). The lack of practical capabilities directly leads students to develop misconceptions, especially when it comes to comprehending the wave aspects of light, such as interference, diffraction, and polarization. Students who lack practical experiences to witness these phenomena directly are more likely to rely on rote learning or form inaccurate intuitive interpretations, such as viewing light as merely a particle or failing to consider the principle of wave superposition.

Table 1. Research results on difficulties in physics material

| Materials | Percentage (%) |
|---|---|
| Temprature ans Heat | 26 |
| Optics | 25 |
| Statistic Fluids | 21 |
| Elasticity and Hooke's Law | 17 |
| Kinematics | 11 |

These false beliefs ultimately impede mastery of complex subjects like contemporary optics and electromagnetism by causing poor conceptual understanding and making it difficult to relate theory to actual phenomena (Njonge, 2023). This claim is supported by observed at SMA FI Jakarta where absent physics laboratories directly impede student outcomes. Digital simulations consequently emerge as a viable pedagogical alternative (Febriansyah & Pujianto, 2023).

The lack of visual representation in traditional textbooks and the restrictions of real laboratory settings have led to a tremendous growth in the use of simulation technologies in physics education, especially in teaching optics (Banda & Nzabahimana, 2021). Many digital tools, such PhET Interactive Simulations (Bello, 2022), GeoGebra (Solvang & Haglund, 2021) and Tracker Video Analysis (Bhakat et al., 2024), have been used extensively in the last ten years to assist students in understanding abstract ideas like light polarization, interference, and diffraction. Even while these simulations provide dynamic representation, many of them are more general exploring tools than ones intended to aid in the conceptual learning of light wave processes.

GeoGebra presents a promising technological solution, enabling dynamic visualization of scientific concepts to enhance understanding (Gaol, 2023). While proven effective in mathematics education for boosting engagement and comprehension (Hohenwarter & Fuchs, 2022; Papp-Varga, 2008; Tamam & Dasari, 2021), its application to physics specifically optics and light waves remains scarcely researched. This study therefore addresses a critical gap by developing and evaluating GeoGebra-based teaching materials to improve secondary students' mastery of light wave phenomena.

A variety of interactive features in GeoGebra are quite helpful for learning physics, especially when it comes to light waves. The platform offers free, cross-platform online accessibility, dynamic visualization, real-time variable manipulation, and simulations based on mathematics. These characteristics allow students to see firsthand how variations in one variable impact wave phenomena like diffraction and interference.

Teachers can keep an eye on the learning process and spot misconceptions early on with GeoGebra's activity tracking and student exploration history capabilities. GeoGebra is an excellent digital learning tool for enhancing conceptual understanding of optics and dispelling frequent misconceptions because of its accessibility, quick visualization, and interactivity. Based on the aforementioned background, this study was designed to address the following research questions: [1] How feasible is REFECTO as a GeoGebra-based instructional tool in terms of pedagogical, design and technical aspects? [2] How practical is the implementation of REFECTO in teaching, considering ease of use and the responses of teachers and students? [3] How effective is REFECTO in improving student learning outcomes on the topic of light waves, based on pretest-posttest analysis?

The development of GeoGebra-based instructional media for the topic of light waves is critically important, given the abstract nature of physics concepts that are difficult for students to visualize. GeoGebra, as an interactive and dynamic software tool, can transform abstract representations into concrete visual simulations, thereby facilitating deeper conceptual understanding. By harnessing this technological potential, educators can create a more engaging, responsive, and 21st-century-aligned learning environment effectively addressing the persistent challenge of limited instructional media that has long hindered the effectiveness of physics instruction, particularly in the domain of light waves.

## RESEARCH METHODS

This study adopted a Research and Development (R&D) methodology structured around the 4D model comprising (1) Define, (2) Design, (3) Develop and (4) Disseminate stages (Lawhon, 1976). The define stage identifies gaps between learning objectives and existing conditions through needs analysis. The initial Define phase involved comprehensive needs analysis through literature review and student interviews. Several SMA FI Jakarta students participated in a semi-structured interview to discuss their learning experiences, including the challenges and obstacles they faced when taking physics classes there. To find trends, themes, and important concerns arising from the students' viewpoints, thematic analysis was used to analyze the interview transcripts.

This study engaged three participant cohorts: (1) five experts holding Master’s degrees in media design, physics content, and educational linguistics for feasibility validation; (2) three physics teachers from SMA FI Jakarta to evaluate classroom practicality; and (3) one class covering 40 students of Grade XI students participating in phased trials (3 students for one-to-one test, 6 students for small group test, and 31 students for field tests) to measure the practicality and effectiveness of the developed REFECTO. Students were selected via stratified sampling by ability level (high, medium, low) to ensure balanced representation and were actively involved in assessing the module’s usability (practicality) and learning outcomes (effectiveness) through questionnaires, simulations, and pre-/post-tests. Teachers and experts were chosen based on a minimum of 5 years experience in physics education or instructional media development.

Formative evaluation utilized expert/teacher questionnaires (Likert-scale instruments). Summative evaluation relied on standardized pretest- posttest instruments (10 multiple choice items aligned with learning objectives). Analytical procedures followed a five stage framework: 1) Test Instrument and REFECTO Feasibility determination via Aiken’s Validity Index (threshold >0.40) and Cronbach’s alpha reliability (threshold ≥0.60); 2) Practicality analysis through student and teacher response questionnaires; 3) Effectiveness quantification using n-Gain scores (g>0.7 indicating high effectiveness) and Cohen’s d (d>0.8 signifying large effects); 4) Statistical processing in SPSS 22; and 5) Triangulation of qualitative feedback across stakeholder groups to contextualize quantitative outcomes.

Table 2. Blueprint test instrument

| No | Cognitive aspects | Question indicator |
|---|---|---|
| 1 | C3 | Determine the nature of the shadow formed Concave mirror |
| 2 | C3 | Determine the nature of the shadow formed Convex mirror |
| 3 | C4 | Determine the nature of the shadow formed Concave lens |
| 4 | C4 | Determine the nature of the shadow formed Convex lens |
| 5 | C4 | Analyzing the process of light polarization |
| 6 | C3, C4 | Calculate the final intensity value and analyze the light polarization process. |
| 7 | C3 | Calculating the wavelength value |
| 8 | C3 | Determining the interference pattern when the slit value is increased |
| 9 | C3 | Determining the interference pattern when the slit value is increased |
| 10 | C3 | Calculating wavelength |

Feasibility determination aims to measure the suitability of data collection instrument items with the variables to be measured, which are analyzed using the Aiken validity coefficient (Aiken, 1985); (Riani Johan et al., 2023). With category high validity (>0.8), moderate validity (0.4-0.8) and low validity (<0.4). Measuring the practicality of through expert questionnaires and measuring the practicality of teaching materials through user responses (SMF Jugessur, 2022); (Pebriana & Nuryaman, 2023) using Crobach's Alpha internal reliability test for the use of a single instrument with different times and subjects. With a category of very high reliability ($\alpha \geq 0{,}9$), high reliability ($0{,}7 \leq \alpha < 0{,}9$), moderate reliabilitiy ($0{,}6 \leq \alpha < 0{,}7$), low reliability ($0{,}5 \leq \alpha < 0{,}6$) and very low reliability ($\alpha < 0{,}5$).

Effectiveness quantification using n-Gain scores. The N-Gain test was conducted to determine whether there was a difference in learning outcomes before and after the use of teaching materials (Faruq et al., 2025). With category ineffective (<40%), low effective (40%-55%), effective (56%-75%) and very effective (>76%). Measuring the magnitude of the relationship between teaching materials and learning outcomes using Cohen's D Size Effect test (Widyastuti & Airlanda, 2020). Cohen's D Size Effect test is a measure of the significance of the effect produced by one variable on another variable (Yoyana et al., 2025). With category minor effect ($0, < d \leq 0{,}2$), moderate effect ($0{,}2 < d \leq 0{,}5$), major effect ($0{,}5 < d \leq 0{,}8$) and very effect ($d > 0{,}8$).

## RESULTS AND DISCUSSION

This study demonstrates that the developed GeoGebra-based teaching materials for light waves satisfy rigorous standards of feasibility, practicality, and effectiveness. Expert validation yielded consistently high scores: media specialists emphasized intuitive design principles critical for educational technology (Maskar & Dewi, 2020), content experts confirmed curriculum alignment, and linguists endorsed communicative clarity.

### Defining Stage

Bibliometric analysis of 1,000 publications (via Publish or Perish and VosViewer) using keywords 'Light Waves, Optics, Teaching Materials' reveals limited scholarly convergence (Figures 1), indicating underexplored potential in developing light wave-specific instructional resources. Student interviews at SMA FI Jakarta corroborate this gap, highlighting how laboratory unavailability and non-interactive materials induce monotonous learning and compromised outcomes. Digital formats are frequently used to create optical simulations, especially with PhET. GeoGebra, a platform commonly utilized in mathematics teaching, is employed in this research breakthrough. REFECTO shows that physics education can also benefit from the effective, practical, and feasible use of the online GeoGebra platform.

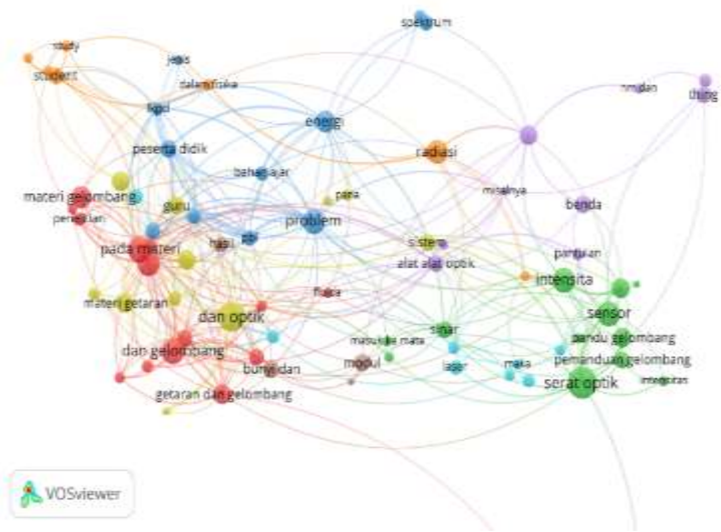


Figure 1. Vosviewer graph of article searches related to light waves, optics and teaching materials

The literature for this study was chosen using a set of predetermined inclusion criteria to ensure relevance, quality, and applicability to the research topic. It was necessary for the chosen studies to:

1. Emphasize teaching physics, especially in the areas of wave optics and light wave phenomena.
2. Involve the use of digital tools, simulations, or interactive visualizations in teaching physics concepts.
3. Report empirical findings related to effectiveness, practicality, or student misconceptions in learning wave optics.
4. Be available in full-text format and accessible for analysis.

Some sources were excluded from the final selection to maintain the literature review's cohesion and emphasis. These include

1. Publications or articles that lacked simulation-based learning environments or interactive digital technologies.
2. Editorials, conference abstracts, or unfinished research with unclear methods or no full-text available.
3. Publications published prior to 2019 unless they were foundational works with a significant impact on citations.
4. Resources that lack academic rigor or are not subjected to peer review, like blog entries or unofficial teaching manuals.

**Design Stage**

The selection of research media using the GeoGebra application/website, which is free and supports geometry materials, is expected to improve student learning outcomes on light waves. The selection of teaching material format was based on the need for interactive visualisation to explain the concepts of interference, diffraction, and polarisation. The format used is an interactive simulation that includes instructions for use, learning tools, learning materials, a pretest, five light wave simulations, independent practice, a posttest, and a learning reflection. GeoGebra allows students to manipulate variables and observe wave patterns directly supporting independent learning.

The instructions for use section provides a flow so that students can use the teaching materials independently. Learning tools include competency outcomes and learning indicators. Pretest is a question to measure students' initial knowledge. The learning material contains an explanation of the concept of light waves and relevant simulations. Posttest is used to evaluate the improvement of students' learning outcomes, and reflection contains the conclusion of learning.

The design of the teaching materials was optimised by media, material, and language experts who provided feedback for improvement. Revisions included adjusting the size of the images, making the materials more interesting, and connecting the concepts to everyday life. The revisions aim to make the teaching materials more feasible and effective in learning light waves.


Figure 2. Initial display


Figure 3. One of the displays of teaching materials

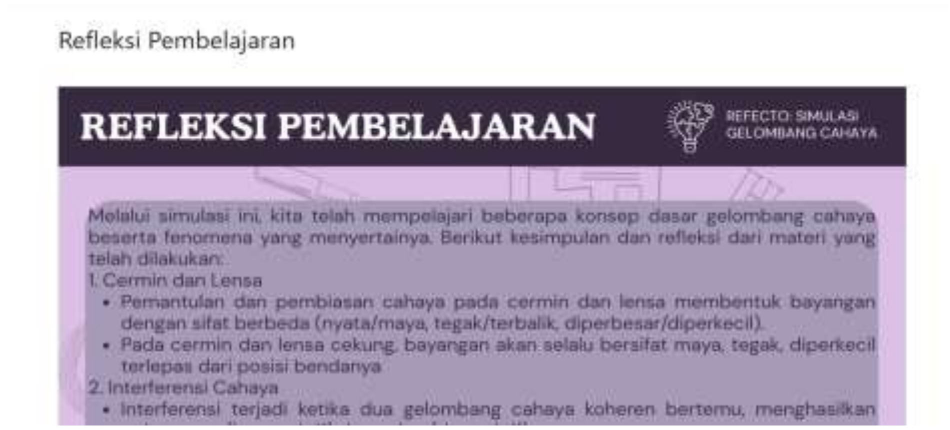


Figure 4. Learning reflections

**Development Stage**

The development stage was conducted with formative testing that refers to (Tessmer, 1993) which includes four stages, namely expert validation, one-to-one test, small group test, and field test. Expert validation involved five media experts, five material experts, and five language experts. The results of media expert validation show an Aiken validity value of 0.91, which means that the media is valid and suitable for use. The material expert validation also shows an Aiken validity value of 0.9 which means that the media is valid and feasible to use. The results of linguist validation also reached an Aiken value of 0.9, confirming that the language aspects in teaching materials are also classified as valid and feasible to use.

Reliability analysis using Cronbach's Alpha internal reliability resulted in a value of 0.76 which indicates high reliability, so this media is suitable for use in further data collection. Quantitative metrics substantiate these assessments, with an Aiken validity index of 0.92 confirming high content validity and Cronbach's alpha reliability of 0.76 indicating robust internal consistency. These findings align with prior research establishing GeoGebra's capacity for enhancing conceptual visualization in wave optics (Kordek & Voda, 2024), while extending its application to address specific pedagogical gaps in physics education.

The development test of the teaching materials was carried out through several stages. First, the one-to-one test was conducted on 3 students from class XI 1 of SMA FI Jakarta who had studied the light waves material. Students were divided based on their level of understanding, namely high, medium, and low. The test results showed an Aiken validity value of 0.89, indicating that the teaching materials are valid and practical to use. Instrument reliability using Cronbach's Alpha obtained a value of 0.72, which falls into the high category.

Furthermore, the small group test listed in was tested on 6 students with an Aiken validity result of 0.86. Teaching materials categorised as practical for learning. Reliability with a value of 0.65 is also classified as moderate but acceptable. After that, the field test was conducted on 31 students who showed an Aiken validity value of 0.90, so that the teaching materials were in the high validity and practical category. Reliability with a value of 0.60 is also classified as moderate but acceptable.

Learner engagement was significantly amplified through interactive simulations, facilitating variable manipulation and real-time observation of wave phenomena factors directly contributing to the 84% N-Gain improvement in learning outcomes. This significant improvement demonstrates that GeoGebra is effective in physics learning, as compared to the study by (Suprapto et al., 2020), where the improvement was 66.67%. The large Cohen's d effect size (4.32) suggests that the intervention was associated with considerable improvements in students' understanding, indicating its potential to enhance learning outcomes. This result is consistent with reserach of (Prayitno et al., 2023); (Putri, A., 2020), who used GeoGebra to study wave optics and found a Cohen's d value of 2.15. It attests to the fact that interactive visual aids significantly improve students conceptual understanding.

Table 3. Pretest and posttest results

| Measures of Central Tendency and Data Dispersion | Pretest | Posttest |
|---|---|---|
| Highest Score | 60 | 100 |
| Lowest Score | 0 | 60 |
| Mean | 33.06 | 89.03 |
| Mode | 35 | 90 |
| N-Gain | | 0.84 (84%) |
| Size effect Cohen's D | | 4,32 |

These findings support well-established theories of learning and demonstrate how GeoGebra's interactive elements successfully operationalize important pedagogical ideas. (Mayer, 2009) Cognitive Theory of Multimedia Learning states that when students are given complementing verbal and visual representations, dual coding that improves conceptual understanding takes place, leading to meaningful learning. This idea is supported by GeoGebra, which combines mathematical formulas and written explanations with dynamic representations like diffraction diagrams and wave interference patterns. Students are able to explicitly connect abstract physics ideas with their tangible applications because to this dual-channel processing.

This study is in line with previous studies by (Fitra & Sitorus, 2021) which revealed that GeoGebra can present material with clear and interactive visualizations, thereby facilitating the understanding of light wave concepts with valid and reliable results. (Sabrina et al., 2023) also highlighted the use of GeoGebra-based teaching materials, which have been proven to be suitable for use in learning. Interactive simulations in learning materials provide students with the opportunity to independently explore concepts of light waves, such as reflection, refraction, interference, diffraction, and polarization, which will deepen their understanding and improve learning outcomes. This is also in line with research (Ahmad, B., Rachmawati, Y. & Suryani, 2019) which shows that computer-based simulations are effective in improving understanding of physics concepts. Research conducted by (Juandi et al., 2021);(Batiibwe, 2024); (Akhirni & Mahmudi, 2015) also supports the findings of studies on the effectiveness of using Geogebra-based teaching materials in learning.

Furthermore, (Bruner, 1966) concept of enactive representation underscores the critical role of active engagement in the construction of knowledge. This theoretical perspective is practically embodied through GeoGebra's interactive manipulation features, which enable learners to dynamically adjust key variables such as phase difference, slit width, and wavelength and immediately observe their impact on wave phenomena. By engaging in this process of direct experimentation, students move beyond passive information reception toward an active, experiential mode of learning, wherein conceptual understanding is reinforced through kinesthetic interaction and real-time feedback.

This technology approach is supported by recent studies that highlight GeoGebra's ability to promote interactive STEM participation and debunk prevalent fallacies in physics teaching. Its mathematical underpinnings provide scientifically correct simulations, and its cross-platform accessibility guarantees that students can interact with the content at any time and from any location. Inquiry-based learning is promoted by features like real-time variable manipulation, which allow students to investigate cause-and-effect linkages, such as how altering the distance between two slits affects interference fringes. Additionally, GeoGebra's exploration history and activity tracking features give teachers insightful information about each student's development and enable prompt correction of misconceptions. Together, these affordances place GeoGebra not just as a visualization tool but as a whole digital environment that facilitates in-depth conceptual learning in optics, based on both useful pedagogy and cognitive theory. Recent studies corroborate this technological approach, noting GeoGebra's effectiveness in fostering interactive STEM engagement (Ziatdinov & Valles, 2022) (Batiibwe, 2024).

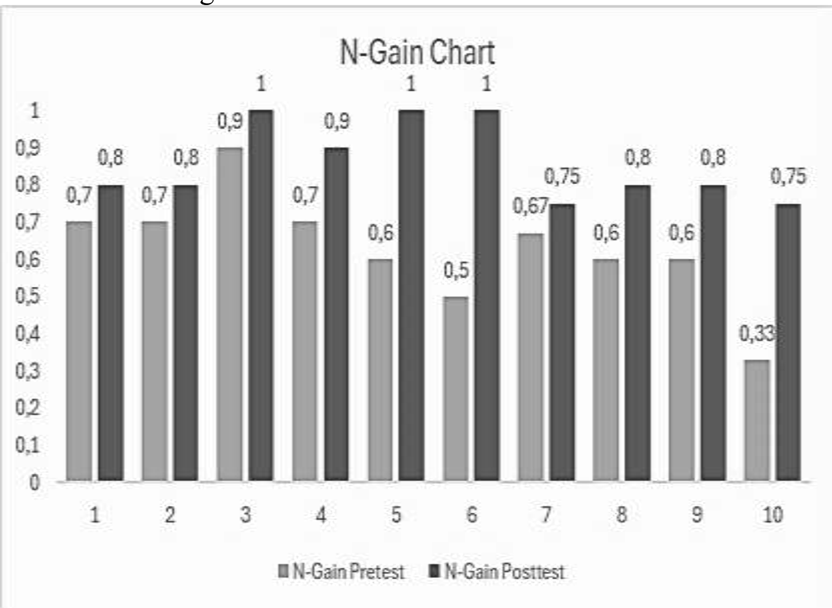


Figure 5. N-Gain score diagram per question

The responses from 3 teachers also show Aiken's validity of 0.85, which means that this teaching material is very valid and practical. The reliability of the teacher's response resulted in a value of 0.60, which is also included in the moderate but acceptable category. The overall results show that the teaching materials developed are feasible, practical and effective in learning. To confirm the validity and reliability of the final test instruments. The instrument test produced a reliability coefficient of 0.60, which is in the moderate range, and an Aiken's validity index of 0.87, which indicates high validity.

Student and teacher feedback highlighted the practicality and effectiveness of the developed materials. Representative responses included:

*"The teaching materials used were already very good. In the future, I hope to return to this school with similar materials for other physics topics, so that learning becomes more effective and encourages students' interest in studying physics."* (Teacher)

"*The teaching materials are easy to use."*

*"The teaching materials are neat and attractive, making them easy to understand."*

*"The teaching materials helped me understand the concepts, especially when the teacher occasionally could not pay full attention to all students."* (Student)

This study has several limitations that should be considered in interpreting its findings and implications. First, there was no control group in the study's one-group pretest-posttest design, which makes it difficult to establish clear causality. Although the GeoGebra-based teaching resources are probably responsible for the noted gains in conceptual understanding, the lack of a comparison group makes it impossible to completely control outside variables like student motivation, extra study time, or contextual impacts. Second, the results cannot be applied outside of the particular school setting where the study was conducted because the distribution of the created instructional materials has not yet been carried out on a larger scale. The socioeconomic backgrounds of the children, the technology infrastructure, and the digital competences of the teachers, all of which could affect the efficiency of the implementation, were not thoroughly investigated.

Future studies should use an experimental or quasi-experimental design with both experimental and control groups to overcome these constraints. This would enhance internal validity and enable more robust causal inferences. It is also necessary to test the resources in a variety of educational environments in order to assess their efficacy, scalability, and adaptability. Using GeoGebra student activity data can yield insightful information about learning habits and guide future developments to better suit the needs of specific students.

Notably, this research extends GeoGebra's utility beyond its traditional mathematical domain into physics education, a novel application highlighted by (Kolář, 2019). The platform's geometric visualization capabilities, multi-platform accessibility, and real-time feedback mechanisms prove particularly advantageous for teaching wave optics, despite certain interface customization constraints. Compared to other educational media, GeoGebra demonstrates superior flexibility and interactivity, offering a dynamic environment where students can manipulate variables, observe phenomena in real time, and construct conceptual understanding more effectively than with static or less responsive tools (Munyaruhengeri et al., 2023). While dissemination remains limited to SMA FI Jakarta during this initial phase, observed outcomes indicate strong potential for broader implementation. Future studies should validate scalability across diverse institutional contexts and develop offline functionality to address connectivity barriers.

Collectively, these findings position REFECTO teaching materials as a viable solution to systemic challenges in optics education. By merging theoretical fidelity with technological innovation, this resource addresses critical infrastructure limitations while demonstrating measurable gains in conceptual mastery, offering educators an empirically validated tool to advance physics pedagogy.

Future studies should use an experimental or quasi-experimental design with both experimental and control groups to overcome these constraints. This would enhance internal validity and enable more robust causal inferences. It is also necessary to test the resources in a variety of educational environments in order to assess their efficacy, scalability, and adaptability. Moreover, efforts should be made to optimize the tool for offline environments to ensure accessibility in areas with limited internet connectivity. By incorporating teacher training modules and fostering community-driven adaptation, REFECTO can evolve into a comprehensive, open-access educational platform that supports equitable STEM learning worldwide.

A teaching material product called REFECTO was developed for light waves for grade XI high school students. This teaching material is designed to help students understand concepts by overcoming laboratory limitations. REFECTO can be accessed online with the link https://bit.ly/OpenAccessREFECTO or student link https://bit.ly/refecto via smartphone or computer, equipped with simulations, pretest-posttest, and instructions for use.

Figure 7. Barcode for open access REFECTO

Figure 8. Barcode for students' access REFECTO

## CONCLUSION

This study successfully developed REFECTO, a GeoGebra-based instructional tool for light wave education, demonstrating robust feasibility, practicality, and effectiveness. Expert validation confirmed high validity (Aiken's V = 0.92) and internal consistency (Cronbach's α = 0.76), ensuring pedagogical and technical rigor. Field testing revealed strong practicality (validity = 0.90; reliability = 0.65). Findings from the one-group pretest-posttest design showed marked improvements in student outcomes, as evidenced by a high n-Gain score (g = 0.84) and large effect size (d = 4.32), suggesting the potential effectiveness of REFECTO in enhancing conceptual understanding of light waves. The implications of this study are particularly relevant for physics education in resource- limited settings, where traditional laboratory infrastructure is often lacking. By leveraging GeoGebra's dynamic visualization capabilities, REFECTO offers an accessible, scalable solution that enhances conceptual mastery in optics, a domain typically challenging to teach through conventional methods.

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