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Application The Adaptive Inquiry Based Learning Model Assisted by PhET Media in Improving Understanding Of Light Concepts

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Abstract

This study aims to test the effectiveness of the application of the Adaptive Inquiry-Based Learning model in science learning in elementary schools. The background of the research raises the problem of low student learning outcomes in abstract light materials. The researcher applied a quasi-experimental method with the Nonequivalent Control Group Design during the research process. The research subjects included 30 grade IV students of SDN Oyom who were divided into two parallel classes. The test instrument collects concept comprehension data through 20 valid and reliable multiple-choice questions. The results of the study showed a significant increase in the experimental class. Students of the experimental class achieved an N-Gain score of 0.91 in the high category. In contrast, students in the control class obtained an N-Gain score of 0.60 in the medium category. The t-test proves a noticeable difference between the two groups. In conclusion, the Adaptive Inquiry-Based Learning model effectively improves the understanding of light concepts through the help of PhET Media.

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INTRODUCTION

Basic education plays a crucial role as an initial foundation in the formation of students' critical thinking, creativity, and problem-solving skills, which are essential skills in the 21st century. In the midst of the dynamics of the rapid development of science and technology, students are no longer only equipped with the ability to memorize facts, but must be trained to construct their own knowledge through the process of scientific investigation. Natural Sciences subjects in elementary schools have a strategic position in developing these skills because of their characteristics that emphasize the understanding of scientific concepts through meaningful learning experiences and empirical observations (Almasri, 2024; O'connor et al., 2021).

One of the essential materials in the science curriculum in elementary school is the concept of light. This material covers a wide range of basic physics phenomena, such as the properties of light propagation, reflection, refraction, and decomposition of light, whose applications are very close to students' daily lives. However, despite being relevant, light materials are often a challenge for students. This is due to the characteristics of the concept of light which tend to be abstract and microscopic. For example, the phenomenon of light refraction or the dualism nature of light is difficult to understand in depth if it relies only on verbal explanations or static two-dimensional image illustrations. Research conducted by Arsyad et al., (2025); Suryani & Purwanti, (2018) confirms that elementary school students often experience visualization difficulties in understanding how light behaves when passing through different mediums, which leads to low mastery of concepts. Understanding the fundamental concepts at this stage is very vital (Cheah, 2020; Kurup et al., 202i; Mustakim, 2025), because it will be a prerequisite knowledge or the main provision for students to learn more complex concepts of optics and physics at the next level of education.

Unfortunately, the reality of implementing learning in the field is often not aligned with these ideal demands. Based on initial observations, the science learning process in elementary schools, especially in research locations, is still dominated by a conventional teacher-centered approach. In this paradigm, the teacher places himself as the only source of information, conveying the subject matter in one direction through the method of lectures in front of the class, while the student is positioned as a passive recipient whose main task is to listen and take notes. As a result, the space for students to explore, ask questions, and develop scientific inquiry skills becomes very limited.

This passive learning condition has a direct impact on the quality of student learning outcomes (Primayana et al., 2019; Musfirayanti et al., 2025), The low cognitive involvement of students in the learning process causes the understanding of the concepts formed to be superficial and easily lost (Tian et al., 2020; van der Graaf et al., 2022). Furthermore, this condition triggers a high level of misconception in students. Various literature studies reveal that misconceptions related to the nature of reflection and refraction of light are very common among elementary school students. Students often fail to relate the theory being taught to the natural phenomena they observe. This empirical fact is a strong indicator that the conventional learning approach that has been applied so far is not effective in facilitating the construction of students' knowledge as a whole. Therefore, a transformation of learning strategies is needed that is able to shift the role of students from passive objects to active subjects of researchers.

The Inquiry-Based Learning (IBL) model has long been widely recognized by education experts as an effective solution to overcome these problems (Arifin et al., 2025). IBL offers a pedagogical framework that puts students in the role of a scientist (Chikaluma et al, 2022; Meulenbroeks et al., 2024). In IBL, students are invited to formulate problems, propose hypotheses, design and conduct experiments, collect data, and draw valid conclusions based on empirical evidence (Chen & Chen, 2025). This process not only trains memory, but also sharpens students' logic thinking and analytical abilities. However, the implementation of pure IBL in heterogeneous classrooms is not without its challenges. Teachers often face technical obstacles, especially in managing time and providing even guidance. Within a classroom, students' abilities are very diverse; Some are able to learn quickly, but others need intensive guidance. In conventional inquiry methods, teachers often struggle to personalize the difficulty of the material and provide targeted scaffolding to each individual in real-time.

To bridge the gap between the demands of inquiry and the diversity of students' abilities, experts developed an innovative approach known as Adaptive Inquiry-Based Learning (AIBL). This model is an evolution of IBL which is integrated with adaptive technology as smart scaffolding. The main advantage of AIBL lies in its ability to automatically detect learning impasses. The intelligent systems in this model are designed to provide personalized feedback or assistance according to the specific needs of each student at the moment. For example, if a student has trouble formulating a hypothesis, the system will provide gradual hints, ranging from visual stimuli to sentence options, without immediately providing a final answer. This mechanism ensures that each student, regardless of their initial ability level, can still follow the inquiry flow to the finish without feeling frustrated. As evidenced by Sari et al.,(2025), this adaptive model is very effective in improving students' learning competence and independence.

In addition to the adaptivity aspect, this study also integrates the use of virtual simulations (virtual laboratories) as the main supporting media. The use of virtual simulations, such as PhET Interactive Simulations, is particularly relevant for teaching abstract material such as light. Simulations allow students to manipulate physics variables that are difficult to do in the real world, such as changing the refractive index of the medium instantly or seeing normal lines and refractive angles with high precision. This multimodal approach strengthens students' conceptual understanding through interactive dynamic visualizations.

This study focuses on the application of the AIBL model assisted by virtual simulation in learning the concept of light at SDN Oyom. The urgency of this research is based on preliminary data that shows that the average learning outcomes of grade IV students on light materials are still low. Students in grades 4A and 4B consistently obtained an average score below the Minimum Completeness Criteria in the previous semester. This low achievement is an urgent signal of the need for innovative interventions to improve the quality of learning. Through this study, the researcher aims to examine in depth how the application of the Adaptive Inquiry-Based Learning model assisted by virtual simulation can be carried out in elementary schools and the extent of its effectiveness in improving learning outcomes and students' understanding of concepts in light materials.

METHOD

The researcher used a quantitative approach with a quasi-experimental method. This study applied the Nonequivalent Control Group Design to compare the two learning groups. Grade IV students of SDN Oyom were the main population in this study. The researcher selected the sample through purposive sampling technique. The sample consisted of 30 students divided into two parallel classes. The researcher used the concept understanding test as the main data collection instrument. This test contains 20 multiple-choice questions covering the cognitive domains C3 and C4. The instrument test resulted in 20 valid questions out of a total of 25 initial questions. The results of the reliability test showed a Cronbach's Alpha coefficient of 0.852 in the very high category.

Research Procedure

1. Teachers carry out learning with *the Adaptive Inquiry syntax* in the experimental classroom:
2. Orientation: Students observe a video of the shallow pool phenomenon at the beginning of the lesson.
3. Formulating Problems: The system provides visual assistance in the form of comparative images if students have difficulty asking questions.
4. Formulating a Hypothesis: The system provides tiered instruction for students who experience thinking barriers.
5. Data Collection: Students use PhET Media to conduct light refraction experiments. The system makes a direct correction in case of an error in the input of the angle measurement data.
6. Conclusion: Students compose a conclusion sentence using *the Guided Construction* feature or sentence puzzle.

Data Analysis Techniques

The researcher analyzed the data through several statistical stages. These stages include a prerequisite test of normality and homogeneity before the hypothesis test. The researchers used the Independent Sample T-Test to test for significant differences with a significance level (α) of 0.05.

The research hypotheses tested are:

- H_a: The application of the Adaptive Inquiry-Based Learning model assisted by PhET Media has a significant influence on improving students' understanding of light concepts.
- H_0: The application of the Adaptive Inquiry-Based Learning model assisted by PhET Media did not have a significant effect on improving students' understanding of light concepts.

The criteria for hypothesis testing are set as follows:

- If the value of Sig. (2-tailed) < 0.05, then H_0 is rejected and H_a is accepted.
- If the value of Sig. (2-tailed) > 0.05, then H_0 is accepted and H_a is rejected.

Finally, the researcher calculated the N-Gain score to measure the improvement in conceptual understanding.

RESULTS AND DISCUSSION

Result

The pretest *data* showed an equal initial condition between the two classes. However, the AIBL model treatment resulted in a significant difference in value improvement after learning.

Table 1. Average Score Recapitulation

Class	Average Pretest	Average Posttest	Gain
Experiment (IV A)	55	96	41
Control (IV B)	58	83	25

Statistical Analysis

Tabel 2. Data Normality Test Results (Shapiro-Wilk)

Class	Data	Statistik	Sig.	Information
Experiment	Pretest	0,905	0,101	Normal (Sig > 0,05)
	Posttest	0,461	0,093	Normal (Sig > 0,05)
Control	Pretest	0,705	0,063	Normal (Sig > 0,05)
	Posttest	0,661	0,071	Normal (Sig > 0,05)

Based on Table 2, the significance value (Sig.) on all *pretest* and *posttest* data in both classes is greater than 0.05. This shows that the data is distributed normally, so it is eligible for the next parametric test.

Table 3. Homogeneity Test Results (Levene's Test)

Data	Levene Statistic	Sig.	Information
Student Learning Outcomes	3,293	0,073	Homogen (Sig > 0,05)

Table 3 shows a significance value of 0.073 which is greater than 0.05. This means that the variance of the data between the experimental class and the control class is homogeneous.

Table 4. Hypothesis Test Results (Paired Sample T-Test)

Pair	Mean Difference	t	df	Sig. (2-tailed)	Information
Pretest - Posttest (Experiment)	-26,533	-26,533	14	0.000	Significant

Based on Table 4, the results of the t-test in the experimental class showed a Sig. (2-tailed) value of 0.000. Because the significance value of 0.000 is smaller than the significance level of 0.05 (0.000 < 0.05), according to the test criteria, H_0 is rejected and H_a is accepted. This proves statistically that the application of the Adaptive Inquiry-Based Learning model assisted by PhET media has a significant influence on improving students' understanding of light concepts.

Effectiveness Test (N-Gain)

Table 5. Effectiveness Test Results (N-Gain)

Class	Average Pretest	Average Posttest	N-Gain	Category
Experiment	55	96	0,91	High
Control	58	83	0,6	Medium

Based on Table 5, the experimental class obtained an N-Gain score of 0.91 which was included in the High category, while the control class obtained a score of 0.60 in the Medium category.

Discussion

This study succeeded in proving that the application of *the Adaptive Inquiry-Based Learning* (AIBL) model assisted by virtual simulation has a very significant influence on improving students' understanding of the concept of light at SDN Oyom. This success is strongly indicated by the surge in the average score of students in the experimental class which increased drastically from 55 to 96, with *a Normalized Gain* (N-Gain) score of 0.91 which is included in the High category. This achievement far surpassed the control class using conventional learning, where the N-Gain reached only 0.60 (Medium category). Statistically, the t-test results corroborate these findings with a significance value of 0.000, which means that the alternative hypothesis (H_a) is accepted and the null hypothesis (H_0) is rejected. This data provides empirical evidence that AIBL model interventions are much more effective than conventional methods in instilling an understanding of abstract physics concepts.

The main factor for the success of this research lies in the systematic integration between a structured inquiry syntax with an adaptive *scaffolding mechanism* that is responsive to the needs of students. In contrast to control classes that rely on the teacher's explanation in a classical way, the experimental class is facilitated by a system capable of personalizing learning aids. In the Problem Orientation stage, the use of video of real phenomena (swimming pools that look shallow) succeeded in triggering students' cognitive conflicts, arousing curiosity that became the main fuel of the inquiry process. When students enter a more difficult stage such as formulating a hypothesis, adaptive mechanisms work crucially. The system detects students who are impasse and provides tiered interventions, ranging from visual cues to closed-answer options. This keeps students in the "Proximal Development Zone" (ZPD), where tasks aren't so easy to tedious, but not so difficult as to be frustrating. This finding is in line with (Sari et al., 2025) who stated that adaptability in inquiry learning is able to significantly increase student competence because each individual receives a portion of guidance that is in accordance with his or her learning speed.

The success of this research is also strongly supported by the use of PhET Media at the Data Collection stage. (Astalini et al., 2019) emphasized that the use of PhET interactive simulations is very effective as a virtual laboratory because it is able to visualize abstract science concepts into concrete, making it easier for students to understand phenomena that are difficult to observe directly. In line with this, (Barif et al., 2025) found that the integration of PhET in the guided inquiry model provides a significant difference in the cognitive abilities of elementary school students compared to conventional methods. In the context of this study, the PhET allows students to manipulate refraction variables with precision, minimize measurement technical errors, and strengthen conceptual understanding. This advantage is also supported by Wahyuni et al., (2025); Yani & Widiyatmoko, (2023) who stated that the implementation of the learning model with the help of PhET significantly improves students' learning outcomes and critical thinking skills. Furthermore, (Diab et al., 2024; Rayan et al., 2023) highlight that the strength of the PhET lies in its ability to transform science education at the elementary school level by creating an interactive and meaningful learning environment, which is in line with increased motivation and active involvement of students in the discovery process.

The learning process ends with the Drawing Conclusions stage which plays a vital role in consolidating students' understanding. At this stage, the AIBL model facilitates students with *Guided Construction* features or sentence puzzles. Based on observations, elementary school students often have the correct experimental data but have difficulty narrating it into a coherent scientific statement. Through this feature, students are guided to construct sentence blocks that logically connect the premise (density of the medium) with the conclusion (direction of refraction). This mechanism not only helps students compose grammatical sentences, but also ensures the occurrence of *valid cognitive closure*. Students become aware of the cause-and-effect relationship they have investigated, so that the understanding of concepts becomes more complete and not easily forgotten. This is in significant contrast to the control class, where students are often confused about deducing their own observations without a clear support structure.

Furthermore, the success of this model can also be seen from the aspects of student *engagement* and independence. In the AIBL model, students are positioned as active subjects who "discover" knowledge, not just recipients. The process of drawing conclusions using *the Guided Construction* feature (sentence puzzle) helps students string together causal logic with scientific but simple language. This multimodal approach, which combines text, video, interactive simulations, and adaptive feedback, has been shown to strengthen student memory retention. As explained by Gunawan et al., (2025) a multimodal approach in science learning effectively accommodates a wide range of student learning styles and deepens conceptual understanding. On the other hand, in the control class, despite the improvement in learning outcomes, observations showed that students' understanding tended to be memorized and less profound due to the lack of direct experience in manipulating physics variables. Thus, it can be concluded that the synergy between inquiry pedagogy and adaptive technology in this study not only succeeded in improving academic scores, but also succeeded in creating meaningful, active, and immersive learning experiences for elementary school students.

CONCLUSION

The Adaptive Inquiry-Based Learning model assisted by Media PhET was very well implemented in the experimental classroom. The application of this model creates an active, interactive, and personalized learning atmosphere for each student. The designed learning activities encourage students to be more involved in the concept discovery process. The positive impact of the application of this model can be seen in the significant improvement in the understanding of the concept of light. This is evidenced by the N-Gain score of the experimental class which is much higher than that of the control class.

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