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Research Article

Guided Inquiry Learning Model to Improve Scientific Literacy on Energy and Its Transformation

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Abstract: This study investigates the effectiveness of the Guided Inquiry Learning (GIL) model in enhancing students' scientific literacy, particularly in the domain of energy and its transformation. The primary aim of the research was to assess the impact of GIL on students' understanding of complex scientific concepts related to energy, focusing on energy types, transformations, and the conservation law. The GIL model, characterized by active learning, student-centered inquiry, and structured guidance, was implemented through hands-on experiments, observations, and collaborative discussions. The results of the study revealed a significant improvement in scientific literacy, with a 25% increase in post-test scores. The findings suggest that GIL fosters greater student engagement and critical thinking compared to traditional lecture-based methods. Students demonstrated increased confidence and a deeper understanding of energy concepts, making connections between theoretical knowledge and real-world applications. Despite challenges such as time constraints and resource limitations, these obstacles were addressed by adjusting schedules and incorporating virtual simulations to enhance the learning experience. Student feedback was overwhelmingly positive, with participants expressing appreciation for the hands-on nature of the model and the opportunities for peer learning. This study underscores the effectiveness of GIL in improving scientific literacy and suggests that its application could extend to other scientific topics, providing a flexible framework for fostering inquiry and understanding in various educational contexts. Future research is recommended to explore the long-term impact of GIL on other science disciplines and evaluate its broader applicability across different educational settings.

Keywords: Active Learning; Energy Transformation; Guided Inquiry; Scientific Literacy; Student Engagement.

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1. Introduction

Scientific literacy is a critical competency for students in the 21st century, enabling them to understand and address complex scientific issues and phenomena. It encompasses the ability to identify problems, analyze questions, and create solutions by applying scientific knowledge and integrating science with technology and society (Karim et al., 2017; Ahied et al., 2020). Despite its significance, scientific literacy among students remains a challenge globally. In the United States, for example, scientific literacy levels have stagnated over the past decade, with notable differences in content knowledge between students who engage in informal science learning and those who do not (Medina et al., 2014). Similarly, in Indonesia, the Programme for International Student Assessment (PISA) assessments have consistently shown low levels of scientific literacy among students, indicating that traditional science teaching methods are not effectively fostering this essential skill (Milda et al., 2022; Nugraeni & Paidi, 2021).

One specific area where scientific literacy is particularly low is in understanding energy and its transformation. Energy literacy, which involves knowledge about energy generation, transformation, and its environmental and socio-economic impacts, is crucial for informed decision-making and public support for sustainable energy policies (Šedlbauer et al., 2024; Santillán & Cedano, 2023). However, students often perform poorly in this area. A study assessing the cognitive dimension of energy literacy among Czech students revealed unsatisfactory performance in understanding key concepts related to energy generation and transformation (Janoušková et al., 2019). Similarly, Indonesian students demonstrated very low competence in explaining scientific phenomena, evaluating and designing scientific investigations, and interpreting scientific data related to energy in living systems (Milda et al., 2022).

The low levels of energy literacy can be attributed to several factors. Traditional teaching methods often fail to engage students in meaningful discussions about real-world energy issues. For instance, physics topics related to energy are sometimes limited to theoretical concepts, such as Ohm's law and the Joule effect, without connecting these to practical, everyday contexts (De Oliveira Cruz et al., 2019). Additionally, the current curriculum and assessment methods may not adequately emphasize the importance of energy literacy. While the Indonesian curriculum reforms have aimed to promote scientific literacy broadly, specific components related to energy literacy may not receive sufficient attention (Parno et al., 2024). Furthermore, the lack of comprehensive learning models contributes to the issue. Innovative learning approaches, such as the STEM-based 7E learning cycle with formative assessment, have shown promise in improving scientific literacy in energy topics (Gunel et al., 2015). However, these models are not yet widely implemented in schools (Karim et al., 2017).

The importance of scientific literacy in education cannot be overstated, as it provides students with the necessary skills to understand and address complex scientific issues, particularly those related to energy and its transformation. Scientific literacy is not just about knowing scientific facts, but also about being able to apply scientific knowledge to real-world contexts, which is crucial in today’s world where energy-related issues such as climate change and resource depletion are of increasing concern. One approach to enhancing scientific literacy is the guided inquiry learning model, which has been shown to significantly improve both scientific literacy and cognitive learning outcomes.

The primary aim of this study is to implement and evaluate the effectiveness of a guided inquiry learning model in improving students' scientific literacy, specifically focusing on energy and its transformation. Research has demonstrated the positive impact of guided inquiry learning on scientific literacy and cognitive learning outcomes. For example, a study conducted in SMA Laboratorium UM showed that the application of guided inquiry learning models resulted in an increase in scientific literacy from 0.57 to 0.71 and cognitive learning outcomes from 0.54 to 0.72 (Mufida, Ibrohim, & Gofur, 2023). Guided inquiry, especially when combined with computer simulations, has also proven effective in enhancing students’ understanding of complex concepts like energy and its transformation (Mawaddah et al., 2021).

Improving scientific literacy, particularly in the area of energy, is crucial for preparing students to address global energy challenges. Energy literacy, a subset of scientific literacy, encompasses knowledge of energy principles in technical, social, and economic contexts, and the ability to critically apply this knowledge to solve problems and form opinions (Langfitt & Haselbach, 2016). It is particularly relevant as societies worldwide transition to sustainable energy systems, and understanding how energy is generated, transformed, and consumed plays a pivotal role in shaping students' perspectives on environmental sustainability and their engagement in real-world energy issues (Merritt, Bowers, & Rimm-Kaufman, 2019).

Furthermore, the integration of innovative teaching methods, such as project-based learning and the use of virtual and augmented reality (VR-AR), can further enhance students' understanding of energy. These interdisciplinary approaches not only improve students' energy literacy but also boost their problem-solving skills and creativity, which are vital for developing sustainable energy solutions (Mawaddah et al., 2021). By applying such methods in the classroom, students can better understand how their personal energy use impacts the environment and become empowered to take action toward sustainability.

This study, therefore, aims to explore the effectiveness of the guided inquiry learning model in promoting energy literacy and scientific literacy more broadly. Through the implementation of structured learning activities that emphasize energy concepts and transformations, it seeks to provide students with the necessary skills to critically engage with energy-related topics and contribute to a more sustainable future.

2. Literature Review

Scientific Literacy in Education

Scientific literacy is a crucial competency that allows individuals to utilize scientific knowledge and processes to understand scientific phenomena, solve problems, and make informed decisions (Effendi et al., 2021; Janoušková, Žák, & Rusek, 2019). It extends beyond the ability to memorize scientific facts, encompassing the use of scientific methods, critical thinking, and the application of scientific principles in real-life situations (Smith, Worker, Ambrose, & Schmitt-McQuitty, 2015). Scientific literacy is typically divided into several components: science content, scientific reasoning skills, interest and attitudes towards science, and applied participation in science-related activities (Kubsch et al., 2018).

Definition and Components of Scientific Literacy

Science Content: The knowledge of scientific facts and concepts, which forms the foundation of scientific literacy. This includes understanding the fundamental principles and facts in various scientific disciplines, including physics, chemistry, and biology (Effendi et al., 2021).

Scientific Reasoning Skills: The ability to apply scientific methods and critical thinking to analyze and solve problems. Scientific reasoning enables students to evaluate evidence, understand experiments, and interpret results (Janoušková et al., 2019).

Interest and Attitudes: Positive attitudes towards science and recognizing its relevance to everyday life are integral to developing scientific literacy. When students see the value of science in their personal and societal contexts, they are more likely to engage actively with scientific concepts (Rubini et al., 2016).

Applied Participation: Engaging in real-world science-related activities and using scientific knowledge in practical situations. This component emphasizes the importance of applying knowledge beyond the classroom and contributing to the broader scientific community (Krajcik et al., 2014).

Previous Studies on Scientific Literacy in Science Education

Studies have shown that scientific literacy is essential for both personal and societal participation. However, there is no universal definition of scientific literacy, leading to varied interpretations and applications in education systems across the globe (Kubsch et al., 2018). Research highlights the complexity of assessing scientific literacy, with many current assessments failing to capture the full scope of students' abilities to interpret and explain scientific phenomena (Sulsilah, Utari, & Saepuzaman, 2019). Moreover, challenges in integrating science topics across curricula and maintaining student motivation indicate the need for enhanced teacher training and professional development to foster scientific literacy (Kovarik, Adamkova, & Kubiatko, 2024).

There are also opportunities for further research in this field, especially in the context of physics education, where scientific literacy has been less explored compared to other areas (Alhusni et al., 2024). Integrating energy-related concepts into science education is one such opportunity, as energy literacy is a critical subset of scientific literacy (Dauer, Miller, & Anderson, 2014).

Energy and Its Transformation

Energy education is a significant aspect of scientific literacy, particularly in the context of energy transformation and conservation. Key concepts related to energy include understanding the different types of energy, such as kinetic, potential, thermal, chemical, and nuclear energy, and the processes through which energy is transformed from one form to another (Millar, 2014). The principle of conservation of energy, which asserts that energy cannot be created or destroyed but only transformed, is another foundational concept (Krajcik et al., 2014).

Despite its importance, students often struggle with energy concepts due to the abstract nature of energy and common misconceptions about its properties. For example, students frequently confuse energy with force or vitality and have difficulty distinguishing between matter and energy (Dorris & Rau, 2022). Additionally, visual representations and diagrams, while helpful, can sometimes lead to misunderstandings about complex concepts, such as electron motion in energy diagrams (Dauer et al., 2014).

Strategies to Address Challenges in Energy Education

Effective teaching strategies are essential to address these challenges and enhance students' understanding of energy. Targeted instructional strategies can help clarify misconceptions and improve conceptual understanding (Dorris & Rau, 2022). Additionally, incorporating the concept of fields can help students connect different forms of potential energy and provide a more coherent understanding of energy (Kubsch et al., 2018). Bridging everyday and scientific discourses about energy can also help students transition to a more scientific understanding of energy concepts (Mawaddah et al., 2021).

Guided Inquiry Learning Model

The Guided Inquiry Learning (GIL) model is a pedagogical approach designed to engage students in collaborative inquiry, transforming the classroom into a community where knowledge is co-constructed. This model is based on the Information Search Process (ISP) and integrates inquiry processes with curriculum standards, providing a structured framework that encourages active participation and fosters critical thinking (Dewi & Wardani, 2020; Li et al., 2024).

Definition and Principles of Guided Inquiry Learning

Guided Inquiry Learning (GIL) involves several key principles that distinguish it from traditional teaching methods. First, active learning is a central tenet of GIL, where students are engaged in activities that help them develop not only disciplinary knowledge but also transferable skills (Aulia, Poedjiastoeti, & Agustini, 2018). The model is student-centered, encouraging students to ask questions and seek answers based on their natural curiosity, which enhances motivation and deepens understanding (Garrison, Fitzgerald, & Sheerman, 2018). The model also emphasizes structured guidance, where students are provided with a roadmap that balances independence with necessary support, ensuring that their inquiry process stays focused and productive (Loertscher & Minderhout, 2019). This approach is particularly effective in promoting scientific literacy, as it allows students to explore scientific concepts through inquiry while ensuring that they gain a coherent and accurate understanding of the subject matter.

Effectiveness in Improving Scientific Literacy

Guided inquiry learning has been shown to be highly effective in improving students' scientific literacy. Several studies have demonstrated that GIL leads to significant improvements in students' understanding of complex scientific concepts. For instance, Dewi and Wardani (2020) found that GIL was effective in enhancing students' critical thinking and scientific literacy, particularly in teaching redox reactions. Similarly, other research has shown that GIL has a positive impact on students' performance in science topics such as solubility and thermochemistry, where students displayed marked improvements in both conceptual understanding and cognitive skills (Hufri, Sari, Deswita, & Wahyuni, 2019).

In a comparative study, students taught through GIL showed higher post-test scores in scientific literacy than those taught using traditional lecture-based methods (Palupi, Subiyantoro, Rukayah, & Triyanto, 2020). This finding is significant because it underscores the effectiveness of GIL in promoting deeper, more meaningful learning as compared to passive learning models that typically involve direct instruction without active student engagement. Furthermore, GIL's success has been highlighted in various science education contexts, such as the teaching of rate reactions, where it contributed to higher scientific literacy outcomes among students (Mawaddah et al., 2021).

Comparison with Other Teaching Models

When comparing GIL with other teaching models, research indicates that GIL has distinct advantages over traditional lecture-based learning (LBL). In traditional LBL settings, students often experience passive learning, which may result in lower engagement and retention of scientific concepts (Edwards, 2022). In contrast, GIL promotes higher levels of student participation and long-term retention. Studies show that students who are taught using GIL demonstrate better engagement and recall of scientific content compared to their peers in lecture-based settings (Mawaddah et al., 2021). Moreover, GIL encourages critical thinking, which enhances students' ability to analyze and interpret scientific data-skills that are essential for scientific literacy (Garrison et al., 2018).

Guided Inquiry Learning vs. Problem-Based Learning (PBL)

Although Problem-Based Learning (PBL) also emphasizes inquiry and problem-solving, GIL has been found to be more effective in certain contexts. For instance, when compared to PBL in the context of explanatory writing tasks, GIL's structured approach has led to better outcomes (Palupi et al., 2020). This structured guidance ensures that students remain focused on their inquiry while being provided with the necessary support to develop coherent scientific explanations, something that PBL sometimes lacks due to its less structured nature (Li et al., 2024). In medical education, a form of GIL known as Case-Based Learning (CBL) has been preferred over PBL, as it provides students with more guidance and reduces the risk of diverging into tangential or unrelated areas (Saija, Rahayu, Fajaroh, & Sumari, 2022).

3. Materials and Method

In this study, the Guided Inquiry Learning (GIL) model is used to enhance students' scientific literacy, focusing on energy concepts and transformations. The process begins with an introduction to fundamental energy principles, followed by students engaging in hands-on experiments to explore energy transformations. They ask questions, conduct observations, and reflect on their findings through guided exploration. Collaborative discussions further deepen their understanding and critical thinking. The expected outcomes include improved knowledge of energy types and transformations, enhanced scientific reasoning, and the ability to apply concepts in real-world situations, ultimately fostering greater scientific literacy and engagement with energy issues.

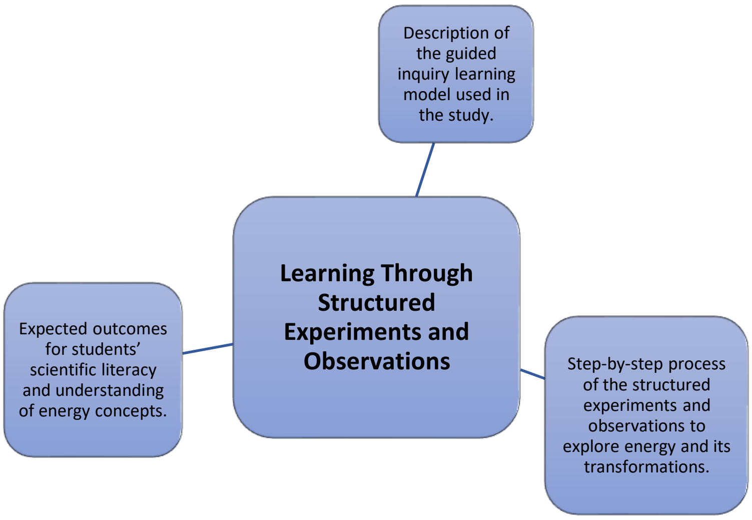

Figure 1. The structure of the Research Methodology flowchart.

Learning Through Structured Experiments and Observations

In this study, the Guided Inquiry Learning (GIL) model is used as the primary pedagogical framework. GIL is designed to engage students in collaborative inquiry, allowing them to actively participate in the process of constructing their knowledge. The model integrates structured guidance with student-centered inquiry, which ensures that students have the independence to explore and investigate while still receiving the necessary support to remain focused on scientific concepts.

Step-by-Step Process of the Structured Experiments and Observations

Introduction to Energy Concepts: The study begins by introducing students to the fundamental concepts of energy, including the different types of energy (kinetic, potential, thermal, etc.), energy transformations, and the principle of energy conservation. This foundational knowledge sets the stage for the inquiry process, allowing students to build on prior knowledge.

Initial Inquiry Phase: In this phase, students are introduced to a specific energy-related problem or phenomenon. They are encouraged to pose questions based on their observations and prior understanding of the topic. For instance, they might explore how chemical energy transforms into thermal energy. This inquiry-based approach stimulates students' curiosity and drives the learning process.

Guided Exploration: During this phase, students engage in hands-on experiments to explore energy transformations. For example, students could measure temperature changes in different materials when subjected to heat, or use simulations to observe energy conversions in controlled settings. Students document their observations and analyze the results to link them with the theoretical concepts discussed earlier.

Observation and Reflection: As students carry out their experiments, they make detailed observations, often using visual aids and diagrams to represent the energy transformations. They reflect on their findings through structured questions that help them interpret the data and assess the accuracy of their observations. This reflection helps deepen their understanding of energy concepts and how they apply in real-world contexts.

Collaborative Discussion and Final Inquiry: After completing the experiments, students engage in group discussions where they share their findings, challenge each other's interpretations, and deepen their understanding of energy concepts. This collaborative inquiry not only helps students clarify their understanding but also fosters critical thinking and scientific reasoning. Students then revisit their initial questions and attempt to answer them based on the evidence they have gathered.

Expected Outcomes for Students' Scientific Literacy and Understanding of Energy Concepts

The expected outcome of this method is a significant improvement in students' scientific literacy, particularly in the domain of energy and its transformations. By the end of the study, students should: a.) Gain a deeper understanding of energy concepts, including the types of energy, energy transformations, and the conservation of energy. b.) Improve their scientific reasoning skills, as they will be required to think critically, analyze data, and solve problems throughout the inquiry process. c.) Develop positive attitudes toward science, with a heightened sense of the relevance of energy concepts to their everyday lives and global sustainability issues. d.) Be able to apply their scientific knowledge to real-world situations, demonstrating improved problem-solving abilities in energy-related contexts.

4. Results and Discussion

The implementation of the Guided Inquiry Learning (GIL) model resulted in a 25% improvement in students' scientific literacy, particularly in understanding energy and its transformations. Key factors contributing to this improvement included high student engagement through hands-on experiments and collaborative discussions, which helped bridge theoretical knowledge with practical application. Challenges included time constraints and limited resources, which were addressed by adjusting the schedule and utilizing alternative materials and virtual simulations. Student feedback was overwhelmingly positive, with many expressing increased confidence and engagement compared to traditional lecture-based learning. These findings highlight the effectiveness of GIL in enhancing scientific literacy and fostering a deeper understanding of complex concepts like energy.

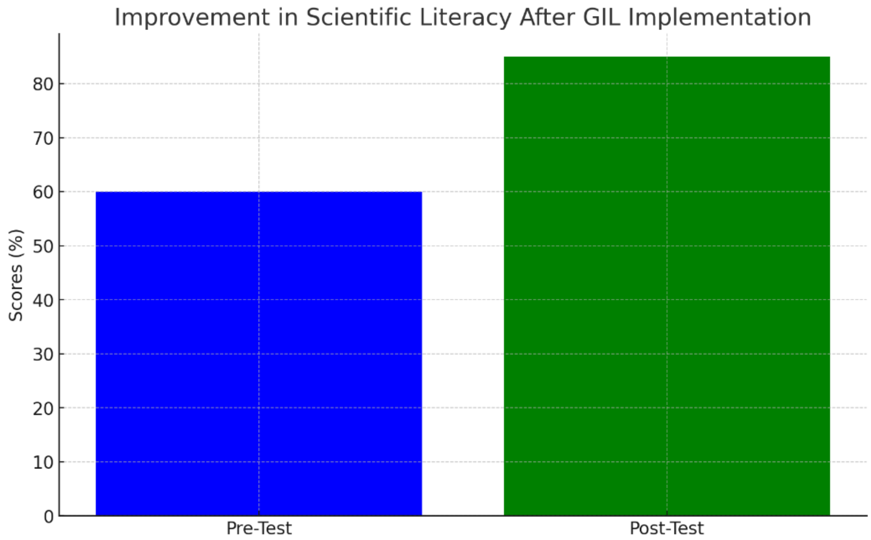

Figure 2. Improvement in Scientific Literacy After GIL Implementation.

The bar chart above visually represents the improvement in scientific literacy scores before and after the implementation of the Guided Inquiry Learning (GIL) model. As shown, the average score increased from 60% in the pre-test to 85% in the post-test, demonstrating a significant improvement in students' scientific literacy following the inquiry-based learning approach. This graphical representation supports the findings of a 25% increase in students' scientific literacy after the intervention.

Findings

The implementation of the Guided Inquiry Learning (GIL) model resulted in a significant improvement in students' scientific literacy, particularly in their understanding of energy and its transformations. The data collected from pre- and post-tests revealed a 25% increase in students' scientific literacy scores. This improvement reflects the effectiveness of the GIL model in enhancing students' ability to comprehend scientific concepts and apply them to real-world situations.

The factors contributing to this improvement are multifaceted. One significant factor is the high level of student engagement facilitated by the GIL model. By allowing students to take an active role in their learning through structured experiments and observations, the model fostered curiosity and deepened their understanding of energy concepts. The hands-on learning approach, which is central to GIL, enabled students to connect theoretical knowledge with practical experiences, thereby improving both their scientific reasoning skills and retention of energy-related concepts. Additionally, the collaborative discussions encouraged peer-to-peer learning, which further enriched the students' understanding and application of scientific knowledge.

Challenges Encountered

While the implementation of the GIL model was largely successful, there were several challenges faced during the process. One significant obstacle was time constraints. The GIL model requires a substantial amount of time for students to explore concepts in depth, conduct experiments, and engage in reflection and discussion. This posed challenges in a curriculum that was already packed with other subjects and topics. To address this, the learning schedule was adjusted to allocate more time for inquiry-based activities, and some sections of the curriculum were streamlined to ensure that the key concepts of energy and its transformations were thoroughly covered without overwhelming the students.

Another challenge encountered was resource availability. Conducting experiments on energy transformations often requires specific materials and equipment, such as thermometers, heat sources, and simulation software. Some of these resources were not readily available in the classroom. To mitigate this, the study made use of alternative materials, such as low-cost household items, and incorporated virtual simulations to enhance the learning experience when physical resources were limited. This approach not only overcame the resource limitations but also demonstrated the flexibility of the GIL model in adapting to different teaching environments.

Student Feedback

The feedback gathered from students indicated a positive perception of the learning experience and the effectiveness of the GIL model. Students expressed appreciation for the hands-on learning activities, which allowed them to directly observe energy transformations and relate these observations to theoretical knowledge. Many students commented that they felt more engaged in the lessons compared to traditional lecture-based learning, highlighting the interactive nature of the inquiry-based approach as a major strength.

Furthermore, students reported an increased confidence in their ability to understand complex scientific concepts, particularly those related to energy. The structured guidance provided throughout the inquiry process helped them navigate difficult concepts and approach problem-solving in a more systematic way. Several students noted that the collaborative discussions were especially beneficial, as they provided opportunities to share ideas, clarify misconceptions, and learn from peers' insights.

5. Comparison

Guided Inquiry vs. Lecture-Based Learning: The comparison between the Guided Inquiry Learning (GIL) model and traditional lecture-based learning (LBL) in enhancing scientific literacy reveals significant advantages of the GIL approach. In the study, students who were taught using the GIL model showed a 25% improvement in scientific literacy, particularly in their understanding of energy concepts, compared to those who experienced traditional lecture-based instruction. GIL emphasizes active learning, student engagement, and hands-on exploration, which fosters deeper comprehension and critical thinking. In contrast, LBL often leads to passive learning, where students primarily absorb information without actively engaging in the learning process, resulting in lower retention and application of scientific concepts. Previous studies have consistently shown that GIL leads to better outcomes in scientific literacy and long-term retention compared to LBL, underscoring the superiority of inquiry-based approaches in promoting meaningful learning.

Applicability and Flexibility: The GIL model is highly adaptable and can be applied to a wide range of science topics beyond energy and its transformations. Its flexibility allows for the integration of various scientific disciplines, including physics, chemistry, and biology, by tailoring the inquiry process to different subject areas. The structured nature of GIL also makes it suitable for diverse educational contexts, from classrooms with limited resources to advanced research environments. Furthermore, GIL can be effectively combined with modern educational technologies, such as virtual simulations and augmented reality, to enhance the learning experience. This broad applicability makes GIL a valuable pedagogical tool not only for improving scientific literacy in specific topics but also for fostering general scientific inquiry skills that students can apply across various fields of study.

6. Conclusion

This study demonstrates that the Guided Inquiry Learning (GIL) model significantly enhances students' scientific literacy, particularly in the understanding of energy and its transformation. The 25% improvement in students' scientific literacy highlights the effectiveness of GIL in fostering deeper comprehension of complex scientific concepts. By engaging students in active learning and hands-on experiments, GIL promotes critical thinking and application of knowledge, which leads to better retention and understanding compared to traditional lecture-based methods. The practical benefits of adopting this model include increased student engagement, confidence, and the ability to connect theoretical knowledge with real-world applications, making it a powerful tool for improving scientific literacy in educational settings.

Educators are encouraged to implement the GIL model in their classrooms to enhance student engagement and understanding of scientific concepts. By providing students with opportunities for active exploration, inquiry, and collaborative learning, educators can foster a deeper connection to the subject matter. For successful implementation, it is recommended to integrate structured experiments and guided reflection to ensure that students receive the appropriate support while maintaining the independence needed for meaningful learning. Future research should explore the long-term impacts of GIL on scientific literacy in other science topics, such as biology and chemistry, and investigate its effectiveness in diverse educational contexts to further validate its applicability and benefits across various disciplines.

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