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The Effect of Guided Inquiry Learning Model on Students' Science Process Skills and Learning Outcomes in Physics Science Lessons

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Abstract – *Science education in the 21st century emphasizes the development of scientific competencies that integrate knowledge acquisition with science process skills (SPS), such as observing, hypothesizing, experimenting, interpreting, and communicating, which are crucial for fostering deep conceptual understanding and improving learning outcomes. However, many students remain passive learners with limited independence, particularly in rural contexts. This results in underdeveloped skills in physics and lower achievement. This study addresses this urgency by examining the effectiveness of the guided inquiry learning model in simultaneously improving SPS and learning outcomes on the topic of waves. A quasi-experimental design was applied, using a non-equivalent control group posttest-only design for SPS and a pretest–posttest control group design for learning outcomes. The sample consisted of 35 eighth-grade students from SMP Negeri 2 Kuta Baro, divided into experimental and control groups. SPS were measured through validated observation sheets, and learning outcomes were assessed using multiple-choice tests. The findings revealed that the guided inquiry group achieved significantly higher in SPS (M = 75.95) than the inquiry group (M = 70.31), with a large effect size (Cohen's d = 0.931). Learning outcomes also improved substantially, with an N-Gain of 75.97% (high category) compared to 68.59% (moderate category) in the control group, yielding a medium effect size (d = 0.609). In conclusion, guided inquiry learning, supported by teacher scaffolding, significantly improves students' SPS and conceptual understanding of wave phenomena. The novelty of this study lies in the simultaneous analysis of SPS and learning outcomes within one instructional framework. This study contributes to physics education by validating guided inquiry as an effective approach to foster active engagement, higher-order thinking, and meaningful learning, especially among passive learners in diverse educational contexts.*

Keywords: *guided inquiry learning; learning outcomes; physics education; science process skills; waves concept*

I. INTRODUCTION

The demands of 21st-century education have significantly transformed science learning, compelling students to acquire not only knowledge of scientific facts but also the skills to investigate phenomena, apply methods of inquiry, and solve complex problems. Education in science and physics, in particular, plays a crucial role in fostering the so-called four C: critical thinking, creativity, collaboration, and communication that are required to prepare students for participation in a rapidly evolving technological society (Alwanda et al., 2024; Budiyono & Hartini, 2016; Irnidayanti & Fadhilah, 2023). Within this context, science process skills (SPS) have emerged as a cornerstone of science education. SPS encompasses a wide range of interrelated competencies, such as observing, hypothesizing, designing experiments, testing predictions, interpreting results, and drawing conclusions. These skills serve as a bridge between scientific knowledge and practice, enabling students to engage in authentic scientific reasoning and fostering deep conceptual understanding (Samadun et al., 2023). By acquiring SPS, students not only master the principles of science but also learn how science develops and how it can be applied in everyday life, thus contributing to improved learning outcomes across science and physics domains (Wahyuni et al., 2024; Amarta et al., 2018).

Several studies confirm that SPS have a strong positive relationship with learning outcomes. For example, Wahyuni et al. (2024) demonstrated that enhancing SPS among elementary students substantially improved their academic performance, while Amarta et al. (2018) highlighted that the emphasis on SPS in the 2013 curriculum in Indonesia encouraged students to move beyond rote learning towards inquiry-based exploration. These findings underscore the necessity of learning models that not only promote knowledge acquisition but also actively engage students in the development of SPS. In line with this, inquiry-based learning approaches have been widely recognized as effective in fostering scientific reasoning, problem-solving skills, and a deeper conceptual understanding. Inquiry learning positions students as active participants in knowledge construction by involving them in processes of questioning, investigation, and discovery (Fang et al., 2016). Among the various inquiry-based approaches, the guided inquiry learning model stands out as a pedagogical design that balances student autonomy with teacher scaffolding, thereby addressing both the need for active engagement and the challenges posed by insufficient learner independence.

Despite its recognized importance, the implementation of SPS in science classrooms remains inconsistent and often inadequate. Many students remain unable to formulate meaningful hypotheses, design valid experiments, or interpret data accurately, indicating weaknesses in the development of higher-order thinking skills. This problem is compounded by the persistence of passive learning cultures in many schools, particularly in rural areas, where students tend to rely heavily on teacher instruction rather than independent exploration (Apriliani et al., 2019; Muliani & Wibawa, 2019). The consequence is that students achieve lower levels of SPS, which in turn affects their conceptual understanding and learning outcomes in science and physics. Addressing these challenges requires pedagogical approaches that can structure learning in ways that empower students to engage actively while simultaneously providing sufficient guidance to prevent misconceptions and enhance scientific reasoning. Guided inquiry, which incorporates explicit teacher support within an inquiry framework, has been proposed as a promising solution to this challenge.

The guided inquiry learning model provides structured opportunities for students to conduct scientific investigations under the guidance of teachers who scaffold the inquiry process. In contrast to unguided or free inquiry, guided inquiry maintains a balance between autonomy and support, ensuring that students are not overwhelmed by the complexities of scientific investigation while still encouraging them to think critically and independently (Fang et al., 2016). Previous studies indicate that this model significantly enhances students' SPS as well as their learning outcomes. For instance, Afrianti et al. (2022) reported that STEM-based worksheets designed around guided inquiry principles achieved an N-Gain of 0.78 in SPS improvement, demonstrating a substantial effect. Similarly, improvements were particularly evident in students' ability to formulate hypotheses and plan experiments, two of the most cognitively demanding components of SPS. Moreover, teacher guidance during guided inquiry is essential in rural schools with low student participation, where learners require more support to engage in inquiry processes successfully (Apriliani et al., 2019; Muliani & Wibawa, 2019).

At the junior high school level, Iswatun et al. (2017) demonstrated that the application of the guided inquiry model improved SPS to a moderate level while also establishing a clear positive correlation between process skills and student learning outcomes. Similarly, Hasmawati et al. (2023) observed that guided inquiry improved SPS in high school students, particularly in subjects such as Dynamic Electricity. Other studies further confirmed that guided inquiry is effective not only in fostering SPS but also in enhancing students' critical thinking skills (Ryoo & Linn, 2016). The development of STEM-based learning materials incorporating guided inquiry also led to significant improvements in students' ability to perform scientific procedures and analyze concepts deeply (Afrianti et al., 2022). Collectively, this body of evidence suggests that guided inquiry can strengthen both the procedural and conceptual dimensions of science learning, making it an effective strategy to address the dual challenges of underdeveloped SPS and limited learning outcomes in physics education.

Nevertheless, while the positive effects of guided inquiry on both SPS and learning outcomes are well-documented, a notable research gap remains: few studies have simultaneously examined both variables within a single research framework and assessed their relationship through comprehensive statistical analyses, including effect sizes. Most existing research either focuses on SPS in isolation or examines learning outcomes without explicitly measuring the contributions of SPS. This fragmented approach limits the ability to fully understand the extent to which SPS improvements translate into better learning outcomes. Consequently, a more integrative study design is necessary to explore how the guided inquiry model impacts SPS and, in turn, contributes to improvements in students' conceptual understanding and performance in physics. Addressing this gap is particularly crucial in rural contexts, where students' passive learning behaviors and limited independence exacerbate the challenges of achieving meaningful educational outcomes.

In this regard, the present study positions itself within the broader literature on guided inquiry by specifically targeting its dual impact on SPS and learning outcomes in physics education. By focusing on the topic of waves, a subfield of physics that requires both conceptual reasoning and procedural application, the study aims to provide a more comprehensive account of how guided inquiry facilitates scientific learning. The choice of waves as a subject matter is relevant because it often poses challenges for students due to its abstract nature, requiring both mathematical reasoning and experimental interpretation. Furthermore, this study is situated in SMP Negeri 2 Kuta Baro, a rural school context where preliminary observations indicated that students exhibit low initiative and high dependence on teacher direction. This aligns with Vygotsky's (1978) theoretical perspective, which emphasizes that learners with limited independence benefit from structured guidance in the zone of proximal development. Guided inquiry, by design, operationalizes this principle by providing systematic scaffolding while still allowing students to engage in authentic inquiry.

Therefore, the present research aims to examine whether the guided inquiry learning model can significantly improve both students' SPS and their learning outcomes in physics, specifically in the subtopic of waves. Unlike previous studies that investigated these variables separately, this study adopts a comprehensive approach by analyzing both dimensions concurrently and assessing their practical impact through statistical significance testing and effect size measurement. In doing so, this study seeks to fill the identified research gap and provide a clearer picture of the pedagogical value of guided inquiry in physics education. The novelty of this study lies in its dual focus, integrative methodology, and contextual application in a rural school setting. The findings are expected to contribute both theoretically and practically.

II. METHODS

This study adopted a quasi-experimental design with a quantitative approach to investigate the effects of the guided inquiry learning model on students' SPS and physics learning outcomes. Quasi-experimental designs are frequently employed in educational research when random assignment is not feasible, as they enable researchers to compare treatment and control groups while still acknowledging certain limitations in equivalence (Sugiyono, 2018; Lakens, 2013). Given the classroom context of this study, full randomization was not feasible, making a quasi-experimental design the most suitable choice for balancing internal validity and ecological validity.

For the measurement of SPS, a non-equivalent control group posttest-only design was applied. This choice was necessitated by the fact that SPS were observed only during the learning process, with no pretest data available for this variable. Consequently, comparisons between the two groups relied on posttest data, recognizing that initial SPS differences may have existed and thus acknowledging this as a limitation. The research design for SPS is presented in Table 1. This design, while less robust than pretest-posttest structures, has been considered adequate in prior studies investigating inquiry-based models when baseline measures are unavailable (Amarta et al., 2018; Sibiç & Şeşen, 2022).

Table 1. SPS observation design (non-equivalent posttest-only control group design)

Group	Treatment	Posttest
Guided inquiry group	X_1	O_1
Inquiry group	X_2	O_2

Where:
X_1 = Guided inquiry group
X_2 = Inquiry group
O_1 and O_2 = SPS performance outcomes

In parallel, for learning outcomes, a pretest–posttest control group design was employed, enabling researchers to measure changes in students' conceptual understanding before and after instruction. This design allows for the comparison of pre-instruction knowledge levels and the subsequent impact of the guided inquiry intervention. The design framework is presented in Table 2.

Table 2. Research design plan (pretest–posttest control group design)

Group	Pretest	Treatment	Posttest
Guided inquiry group	O_1	X_1	O_3
Inquiry group	O_2	X_2	O_4

Where:
X_1 = Learning with an inquiry model guided
X_2 = Learning with inquiry model
O_1; O_2 = Pretest in each group
O_3; O_4 = Posttest in each group

The study was conducted at SMP Negeri 2 Kuta Baro, located in Aceh Besar Regency. The population comprised eighth-grade students, from whom two classes were purposively selected as the research sample. A total of 35 students participated, with 16 students in class VIII-A designated as the experimental group and 19 students in class VIII-C as the control group. Several considerations justified purposive sampling: students in these classes were cooperative, demonstrated varied levels of SPS, and shared relatively similar initial cognitive, psychomotor, and affective characteristics. To minimize teacher-related biases, both groups were taught by the same instructor using virtual experiments as a unifying instructional medium. Virtual experiments have previously been shown to reduce teacher-centered variation and enhance objectivity in science education research (Ilies et al., 2015; Yeoh et al., 2025).

The instruments for data collection consisted of SPS observation sheets and a multiple-choice test for learning outcomes. The SPS observation sheet was adapted from validated frameworks provided by Amarta et al. (2018) and Sibiç and Şeşen (2022), with modifications to suit the specific physics context of wave phenomena. The instrument assessed a wide range of SPS indicators, including observing, grouping, hypothesizing, planning experiments, interpreting data, using tools and materials, applying concepts, and communicating. These indicators reflect the core competencies emphasized in prior literature on science education reform (Fang et al., 2016; Fadhilla et al., 2021). To quantify student performance, categorical observations were converted into continuous percentage scores using the normalized percentage equation

$$NP = \frac{R}{SM} 100\% \qquad (1)$$

Explanation:
NP = Percentage value of the SPS
R = Score obtained by students
SM = Ideal maximum score
100 = Fixed number

Table 3. The SPS criteria (Amarta et al., 2018)

Percentage score	**Criteria**
76-100%	Very good
51-75%	Good
26-50%	Not good
0-25%	Very bad

For learning outcomes, a 15-item multiple-choice test was designed to assess conceptual understanding of wave principles and applications. Instrument validity was established through expert judgment: two validators (a physics expert and a science education expert) reviewed the items for content relevance, clarity, and feasibility. Such validation aligns with best practices in educational measurement (Cohen, 1992; Gravetter & Wallnau, 2016).

The procedure for data collection followed a structured sequence. Initially, pretests were administered to both groups to establish baseline knowledge levels (O_1 and O_2). During the instructional phase, the experimental group engaged in learning activities guided by the principles of the Guided Inquiry Model, while the control group followed a conventional inquiry approach.

Both groups utilized virtual experiments to investigate wave-related phenomena, thereby ensuring parity in the mode of instruction and isolating the role of guided teacher support as the distinguishing factor. During these sessions, SPS were observed systematically through the adapted observation sheets, yielding posttest data O_1 (guided inquiry group) and O_2 (inquiry group). After instruction, both groups completed a posttest (O_3 and O_4) designed to measure learning outcomes.

Data analysis was conducted using multiple statistical procedures to ensure comprehensive interpretation. First, normality was tested using the Shapiro-Wilk test at a significance level of $\alpha = 0.05$, given its suitability for small sample sizes (Gravetter & Wallnau, 2016). Homogeneity of variance was examined using the F-test at the same significance level. These tests confirmed whether the data met the assumptions for parametric analysis. For normally distributed and homogeneous data, independent-sample t-tests were employed to examine significant differences between groups, whereas for non-normal or heterogeneous data, the Mann-Whitney U test was used as a non-parametric alternative (Sugiyono, 2018).

To evaluate the extent of learning improvements, normalized gain (N-Gain) scores were calculated using the formula proposed by Hake (1998) :

$$\text{N-Gain} = \frac{\text{skor posttest} - \text{skor pretest}}{\text{skor ideal} - \text{skor pretest}} \quad (2)$$

Improvement results are interpreted in accordance with the guidelines in Table 4.

Table 4. N-Gain test interpretation category

N-Gain Value	Category
≥ 0.70	High
0.30 ≤ g ≤ 0.70	Moderate
< 0.30	Low

The practical influence of the Guided Inquiry model on SPS and learning outcomes was calculated using Cohen's d (Cohen, 1988; Lakens, 2013; Gravetter & Wallnau, 2016). Meaning from Cohen's value of the size effect based on the criteria in Table 5. This approach aligns with recommendations to complement significance testing with effect size reporting, thereby enhancing the interpretive power of educational research findings (Lakens, 2013; Juniar & Simbolon, 2023).

Table 5. Cohen's standard interpretation

Value *d*	Effect size category	Practical meaning
< 0.20	Very small	Almost no difference, not practically significant
0.20-0.49	Small	Limited influence, not essentially significant
0.50-0.79	Medium	Meaningful influence, worthy of consideration
≥ 0.80	Large	Strong influence, practically and educationally significant

III. RESULTS AND DISCUSSION

3.1 SPS

The findings of this study revealed that students who learned through the guided inquiry model consistently achieved higher SPS scores compared to those taught using the inquiry model. Figure 1 illustrates the comparison of SPS performance between the guided inquiry and inquiry groups across several indicators. The data show that the guided inquiry group consistently achieved higher percentages in almost all SPS aspects, including observing, interpreting data, using tools and materials, applying concepts, formulating hypotheses, and communicating results. The largest improvement appeared in the indicators of formulating hypotheses and designing experiments, indicating that students in the guided inquiry class developed stronger analytical and reasoning abilities when supported with structured teacher guidance. Meanwhile, the smallest difference was observed in the grouping skill, where both groups obtained relatively similar results.

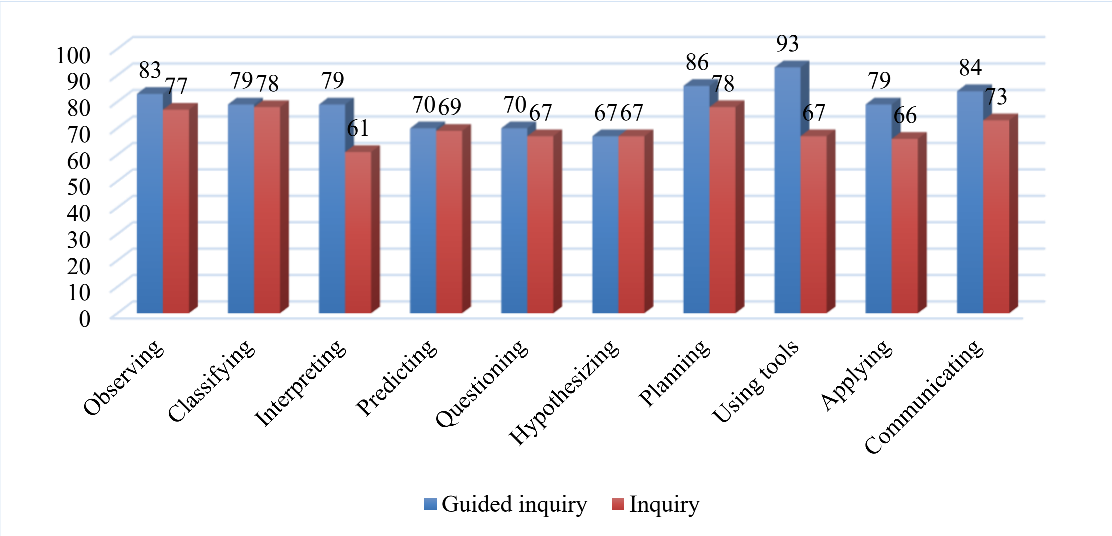

Figure 1. Comparison of the percentage of observation results of guided inquiry treatment class and the inquiry treatment class

Statistical analysis supported these findings. The Mann-Whitney U test revealed that the median SPS score of the guided inquiry group was significantly higher than that of the inquiry group ($U = 47.5 <$ U-table $= 68.0$, $p < 0.05$). Moreover, the effect size was large (Cohen's $d = 0.931$), indicating a substantial practical impact. This demonstrates that the guided inquiry model not only produced statistically significant improvements but also led to meaningful gains in students' SPS. According to Liliawati et al. (2018) and Farhan et al. (2021), large effect sizes in SPS outcomes reflect enhanced higher-order thinking processes such as analysis, synthesis, and problem-solving skills that are foundational for long-term scientific literacy.

These findings suggest that guided inquiry provides more effective scaffolding in developing complex SPS components, especially those requiring higher cognitive involvement. Students benefited from teacher-led questioning, feedback, and structured experimental design stages that guided them in understanding and applying scientific concepts. This result aligns with the findings of Nurwahidah (2023) and Nurlina (2020), who emphasized that systematic scaffolding in guided inquiry helps learners formulate hypotheses and plan experiments more effectively. Similarly, Afrianti et al. (2022) and Ayuningsih et al., (2022) found that guided inquiry fosters authentic scientific investigation skills by encouraging students to think critically, make predictions, and validate ideas through evidence-based reasoning. Overall, the trend in Figure 1 reinforces the view that structured inquiry-based learning promotes the mastery of higher-order scientific skills, confirming earlier reports that effective teacher guidance plays a key role in helping students overcome difficulties in advanced SPS indicators (Asrizal et al., 2018; Hasmawati et al., 2023; Iswatun et al., 2017; Nur, 2019)

3.2 Learning outcomes

In addition to SPS, the study assessed students' cognitive learning outcomes in physics, as measured by pretest and posttest scores. The results demonstrate that students taught with the Guided Inquiry model achieved significantly higher posttest scores than their counterparts in the Inquiry group. Improvements were measured using N-Gain, which accounts for initial differences in students' prior knowledge. As illustrated in Figure 2, the average N-Gain for the guided inquiry group was 75.97%, placing it in the high category. In comparison, the Inquiry group achieved an average N-Gain of 68.59%, which falls into the moderate category. This indicates that students under guided inquiry instruction not only learned more but also achieved deeper conceptual understanding compared to those taught through unguided inquiry.

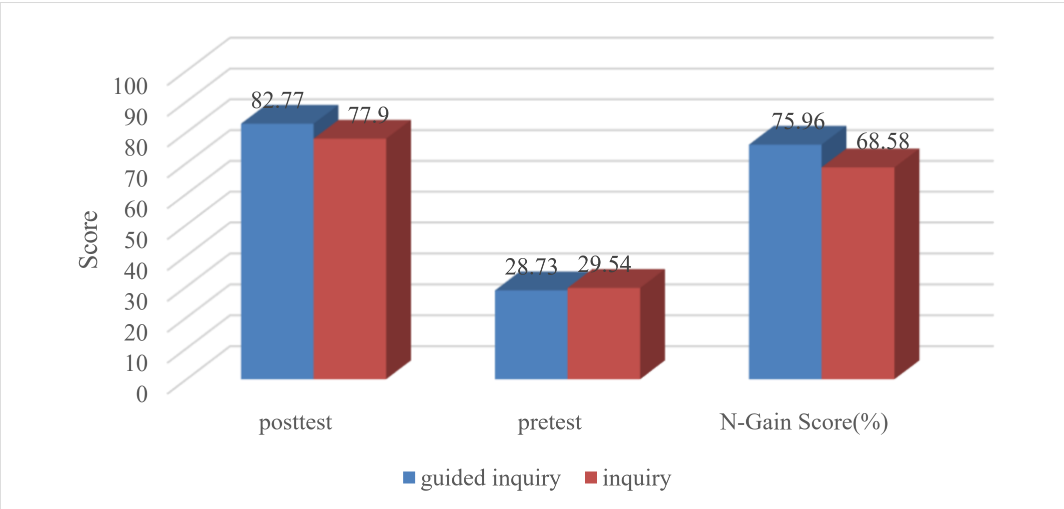

Figure 2. Average results of pretest, posttest, and percentage of N-gain

Statistical testing confirmed these results. The independent-samples t-test revealed that the posttest scores of the guided inquiry group were significantly higher than those of the inquiry group ($p < 0.05$). Moreover, the effect size calculated using Cohen's d was 0.609, which falls within the medium category. This suggests that the Guided Inquiry model had a moderate but meaningful influence on student learning outcomes, echoing findings from Lakens (2013) and Juniar and Simbolon (2023) that medium effect sizes represent educationally important improvements.

These findings are consistent with results from previous meta-analyses. Walker and Warfa (2017) reported that guided inquiry produced small to moderate gains in student achievement, while Ananda & Usmeldi (2023) found effect sizes as high as 1.45 in certain contexts, indicating the variability of outcomes depending on the subject matter and instructional implementation. In this study, the medium effect size suggests that guided inquiry is particularly effective in contexts where students require structured support to grasp complex and abstract physics concepts such as waves.

A key aspect of this study is the observed correlation between improvements in SPS and gains in learning outcomes. The data indicate that students who demonstrated higher proficiency in SPS also tended to achieve higher posttest scores. This finding supports the theoretical perspective that SPS act as mediators for learning, whereby students' ability to observe, hypothesize, and interpret data enhances their capacity to understand and apply physics concepts (Nurlaili et al., 2020; Fadhilla et al., 2021; Zahrina et al., 2020). The strong correlation between SPS and learning outcomes in this study is further supported by literature on scaffolding in science learning, which emphasizes that effective guidance in scientific processes fosters both procedural fluency and conceptual mastery (Ilies et al., 2015; Yeoh et al., 2025).

The present findings reinforce a growing body of evidence that structured inquiry environments can substantially advance students' scientific competencies. Students taught with the guided inquiry learning model demonstrated superior SPS relative to peers in the unguided Inquiry condition, with particularly pronounced gains in higher-order indicators—interpreting data, using tools and materials, applying concepts, formulating hypotheses, and communicating results. These outcomes are consistent with studies showing that inquiry models, which deliberately incorporate scaffolding, are better positioned to cultivate sophisticated forms of scientific reasoning than discovery-oriented approaches that assume high learner independence (Fang et al., 2016; Iswatun et al., 2017; Hasmawati et al., 2023). The magnitude of improvement observed here is a large practical effect on SPS, suggesting that the quality and timing of teacher guidance play a decisive role in enabling students to coordinate procedural and conceptual knowledge during investigations (Liliawati et al., 2018; Farhan et al., 2021).

Guided inquiry's advantage is theoretically coherent with socio-constructivist accounts of learning, in which strategic scaffolding supports novices as they operate within their zones of proximal development (Vygotsky, 1978). In practical terms, students in the guided condition benefited from explicit prompts to generate and refine hypotheses, plan and execute measurements, and interpret evidence with attention to validity and reliability—processes that are frequently underdeveloped when instruction relies on minimally guided exploration. Meta-analytic and design-based reports similarly indicate that structured inquiry promotes more reliable gains in process-oriented competencies than unstructured formats, particularly in contexts where students have limited prior experience with open-ended investigation (Walker & Warfa, 2017; Afrianti et al., 2022). Against this backdrop, the present study adds empirical weight by quantifying the practical significance of the difference: the Guided Inquiry group's SPS advantage corresponded to Cohen's d in the large range, underscoring that the effect is not merely statistically detectable but educationally consequential (Lakens, 2013).

The learning-outcome results complement the SPS pattern. Students in the Guided Inquiry group achieved higher posttest performance, with a medium effect size and a higher normalized gain, compared to the comparison group. This aligns with prior syntheses indicating that guided inquiry tends to yield modest to substantial improvements in achievement, with the exact magnitude being sensitive to topic complexity, implementation fidelity, and the balance of teacher support versus student autonomy (Walker & Warfa, 2017; Ananda & Usmeldi, 2023). The topic of waves is conceptually demanding, requiring coordination of representational forms (verbal, graphical, mathematical) and the linking of macroscopic observations to abstract models. In such domains, well-timed scaffolds reduce extraneous cognitive load and help students allocate working memory to schema construction rather than search, which may explain the observed medium-sized achievement gains in the guided condition (Lakens, 2013; Fang et al., 2016). The pattern also coheres with research showing that improvements in SPS often mediate gains in conceptual understanding and problem solving: students who learn to design fair tests, interpret variability, and justify claims from data tend to transfer these capabilities to novel physics tasks (Nurlaili et al., 2020; Fadhilla et al., 2021; Zahrina et al., 2020; Ilies et al., 2015; Yeoh et al., 2025).

A useful way to interpret the joint SPS–achievement profile is as evidence that guided inquiry supports a productive integration of "knowing how" and "knowing why." The large practical effect on SPS indicates that students learned to enact core practices of science with increasing fluency, while the medium effect on achievement suggests that these practices were leveraged to stabilize and extend conceptual knowledge in waves. That the SPS effect exceeded the achievement effect is not unexpected: procedural fluency can accelerate relatively quickly under scaffolding, whereas consolidation of deep conceptual networks often requires more extended cycles of retrieval, elaboration, and application across contexts (Walker & Warfa, 2017). Still, the high normalized gain for the guided group indicates that conceptual learning kept pace to a meaningful degree, arguably because students' evidence-handling and reasoning practices became more disciplined and explicit (Afrianti et al., 2022).

The study's instructional ecology likely contributed to these effects. Both groups were taught by the same teacher and engaged with virtual experiments, which reduces teacher and media confounds while preserving authentic investigative activity. Virtual experimentation can standardize exposure to phenomena, foreground measurement and model-based reasoning, and lower logistical barriers, thereby creating time and cognitive space for teacher prompts that focus students on the logic of inquiry (Ilies et al., 2015; Yeoh et al., 2025). In rural settings where students often begin with lower self-initiated engagement and fewer opportunities for extended lab work, this blend of controlled experimental access and structured guidance may be particularly beneficial, as reported in prior work on guided inquiry in under-resourced contexts (Apriliani et al., 2019; Muliani & Wibawa, 2019; Iswatun et al., 2017). The present pattern of large SPS effects and moderate achievement gains aligns with the literature and underscores its practical significance through effect-size estimation.

At the same time, the results should be interpreted with appropriate caution in light of design constraints. SPS were measured via a posttest-only non-equivalent control-group design, which acknowledges potential baseline differences across classes. This limitation was partly mitigated by using the same instructor, a common curricular focus (waves), and shared virtual-experiment modalities; nevertheless, residual selection effects cannot be completely ruled out. The pretest–posttest design for achievement strengthens causal attribution, and the consistency of the SPS and achievement patterns increases confidence that the guided scaffolds mattered in practice. Still, triangulating SPS with additional measures (e.g., performance assessments or think-aloud protocols) and extending the design to multiple schools would improve external validity and generalizability (Lakens, 2013; Walker & Warfa, 2017). Notably, the study's internal effect estimates—large for SPS and medium for achievement—fall within the ranges reported in prior meta-analytic and multi-site work, supporting their plausibility and transportability (Walker & Warfa, 2017; Ananda & Usmeldi, 2023).

The implications for pedagogy and design are straightforward. First, in topics with substantial abstraction and multi-representational demands, teachers should explicitly structure the phases of inquiry—problem framing, hypothesis generation, planning, data interpretation, and evidence-based communication—using prompts, worked examples, and feedback cycles that gradually fade as competence increases (Fang et al., 2016; Iswatun et al., 2017). Second, pairing guided inquiry with virtual or blended experiments can create stable practice opportunities and allow teachers to monitor and calibrate the difficulty of tasks in real time, which appears to be a key mechanism for the SPS and achievement improvements observed here (Ilies et al., 2015; Yeoh et al., 2025). Third, investing in teacher professional learning that targets scaffold design—how to cue comparison, highlight causal structure, surface assumptions, and formalize claims—may have high leverage, particularly in schools where students exhibit lower initial autonomy (Apriliani et al., 2019; Muliani & Wibawa, 2019). These recommendations are consistent with the literature reviewed in the Introduction and with the pattern of outcomes documented in the Results.

Finally, this study makes a novel contribution by examining SPS and achievement simultaneously and by quantifying their practical significance in a rural junior high context on the topic of waves. Prior work frequently isolated one outcome or omitted effect-size reporting, limiting insight into how practice gains translate into conceptual performance (Iswatun et al., 2017; Hasmawati et al., 2023; Afrianti et al., 2022). By demonstrating a large SPS effect alongside a medium achievement effect and by situating the results within a controlled instructional ecology, the study clarifies when and how guided inquiry "pays off." Future research can build on this by experimentally manipulating the dosage and timing of scaffolds, by tracing longitudinal retention and transfer, and by testing hybrid models that integrate guided inquiry with cooperative structures or augmented-reality visualizations known to bolster spatial reasoning and vector coordination (Ryoo & Linn, 2016; Yeoh et al., 2025). Together, these trajectories would extend the evidence base for guided inquiry as a robust, scalable approach to advancing scientific practice and understanding in physics classrooms (Lin et al., 2020; Rojas et al., 2019; Zhao et al, 2025).

IV. CONCLUSION AND SUGGESTION

The results of this study demonstrate that the guided inquiry learning model significantly enhanced both students' SPS and their learning outcomes in physics, particularly in the subtopic of waves. Students in the guided inquiry group achieved higher SPS scores than those in the inquiry group, with statistically significant differences and a large practical effect size. Improvements were especially pronounced in advanced indicators such as interpreting data, applying concepts, and communicating results. Similarly, the Guided Inquiry group outperformed the Inquiry group in posttest performance, achieving a higher normalized gain categorized as high, with a medium effect size, indicating meaningful conceptual improvement. Collectively, these findings confirm that guided inquiry provides structured yet engaging learning experiences that effectively integrate process skills with conceptual understanding in science education.

This study, however, has limitations. The relatively small sample size and the use of a non-equivalent posttest-only design for SPS restrict the generalizability of the findings. At the same time, contextual constraints limited the scope to one rural school. Future research should employ randomized controlled trials, larger and more diverse samples, and longitudinal designs to examine the sustainability of improvements in SPS and learning outcomes. Expanding the study to include additional subjects and integrating innovative technologies such as artificial intelligence or augmented reality could further enrich inquiry-based physics education. Despite these limitations, the present study contributes to the wing literature by simultaneously analyzing SPS and learning outcomes, emphasizing their interdependence, and quantifying both statistical and practical significance. In doing so, it advances understanding of how guided inquiry can be optimized to foster meaningful learning in physics and provides evidence-based guidance for educators seeking to strengthen inquiry-based practices in diverse educational contexts.

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