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The effect of the guided inquiry model using PhET simulation media on students' problem-solving ability in static fluid material

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Abstract
This study examines the effect of the guided inquiry model with PhET simulation on students' problem-solving skills in static fluid material. The method used was a pre-experiment with a one-group pretest-posttest design, involving 43 students selected by purposive sampling. Data were obtained through essay tests and analyzed using SPSS 27. Statistical analysis showed a significant increase in problem-solving skills (p = 0.001, <0.05). This 55.79% increase indicates the effectiveness of the PhET-based guided inquiry model in improving students' problem-solving skills. The implication is that this model helps students develop problem-solving skills by guiding them in identifying problems, formulating hypotheses, and evaluating solutions based on static fluid principles. Teachers can adopt this model to guide students in developing systematic and evidence-based problem-solving strategies. Further research is suggested to test its effectiveness on other physics concepts or compare it with direct experimental methods.

Keywords: guided inquiry, PhET simulations, problem-solving, learning technology

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I. Introduction

21st-century education is a characteristic of the globalization era, towards openness to technological and scientific developments. Teachers in this century must dare to create innovations in learning, which are currently being developed into student-centered learning, so that creativity increases and the quality of human resources in education improves. Various aspects of human life have been greatly influenced by advances in science and technology. Information and Communication Technology (ICT) has influenced how we learn and acquire knowledge in education. Through digital technology, the learning process is now more interactive, accessible, and not limited by time and space [1]. Modern education is no longer just about transferring information from teachers to students; it emphasizes empowering students to explore, dig, and construct their knowledge independently. This approach aims to improve students' ability to think critically, creatively, and adaptively to have broad life skills. The main goal is to prepare students to be able to face and solve complex challenges in real life by thinking systematically, innovatively, and constructively [2].

Purposeful, self-directed assessment results in interpretation, analysis, evaluation, and inference, as well as explanation of evidence, concepts, and methods of critical thinking. It reflects tendencies and skills in an activity with reflective skepticism. This assessment assesses information, explains reasons, and solves unknown problems [3]. Learners in the 21st-century are expected to have four main competencies known as the 4Cs: problem-solving and critical thinking skills, communication skills, creativity, and the ability to work collaboratively [4]. These skills, which are categorized as higher-order thinking skills in the 21st-century skills framework, are considered essential for students to prepare for their future [5]. These competencies are indispensable for students to apply, assess, and make informed decisions based on effectively gathered information [6]. This revolutionary period is one in which disruptive innovations are flourishing and making a significant impact, including in the field of education [7]. Science is a field that investigates the nature of nature and covers the physical world, both living and non-living things [8]. Phenomena, conceptions, and principles are not the only topics covered in the arts [9]. Physics lessons come from the development of natural science, which aims to help students focus more on the academic field. Physics lessons are included in science at the junior high school level. In contrast, at the senior high school level, physics lessons stand alone or remain within their learning area [10].

In the school environment, the focus of learning is often limited to mastering and understanding the material, while the ability to apply, analyze, synthesize, and evaluate is rarely emphasized [11]. In schools, there is a tendency for students to only hone science knowledge as something that must be memorized, such as concepts, theories, and laws, with a focus on learning that is more aimed at tests or exams [12]. Lack of interest in learning media [13], lack of variety in the delivery of material [14], as well as models and methods that have not been adapted to the development of technology and information, so that it is still considered outdated [15]. This is supported by students who are the subdued generation [16].

Learning science by the scientific method will instill many scientific attitudes in students, including honesty, openness, tolerance, optimism, courage, and creativity [17]. Students rarely learn to solve problems independently. Instead, they usually only receive information, write and memorize material the teacher provides, and have little experience solving problems independently [18]. This one-way learning makes students less trained in developing problem-solving and analytical skills. In addition, students have difficulty applying the concepts learned in real situations because they do not have many opportunities to actively participate in learning [19]. Physics learning demands innovative approaches that encourage students to actively explore scientific concepts. One approach that has proven successful for improving students' concept understanding and their critical thinking skills is the guided inquiry model, also known as guided inquiry learning [20]. This approach allows students to discover concepts independently with minimal direction from the teacher, thus better understanding the relationship between theory and real phenomena.

Physics Education Technology (PhET) simulations have been widely used in physics learning in recent years. These simulations offer interactive visual representations that help students understand concepts that are difficult to visualize directly [21]. According to previous research, students can better understand concepts and are more motivated to learn [22]. In addition, the guided inquiry model has also been shown to improve students' ability to think critically and solve problems in physics fields such as mechanics and electricity-magnetism [14]. However, not many studies have specifically studied how effective the use of guided inquiry models with similarity.

Previous studies have mostly focused on the application of PhET in mechanical or electrical concepts, while static fluid concepts still receive less attention [23]. However, static fluid concepts such as buoyancy force, hydrostatic pressure, and Archimedes' law are often difficult for students to understand because they are very abstract and require a clear visual understanding. Therefore, this research is needed to fill the gap by looking at how combining the guided inquiry model and PhET simulation can improve students' understanding of static fluid material. This research will also see how effective the combination of the two is in static fluid learning and how it affects students' problem-solving skills. It is hoped that the results of this research will help develop better physics learning approaches, help educators make better use of digital technology, and provide a new perspective on the application of technology-based learning models in the modern era.

Teachers play an important role in making the learning environment fun and cheerful [24]. A teacher needs to be able to use various learning methods innovatively to achieve learning objectives [25]. Efficiently. Teachers should pay attention to students' activities before the lesson starts. The closeness of the teacher to the example is very important to create a cheerful and fun learning environment [26]. Based on the learning process standards, science learning is focused on developing scientific work through discovery activities known as inquiry. Learners should have the basic skills of observing, classifying, interpreting, predicting, applying, planning, and communicating research results [27]. Learners can improve their understanding, communicate better, and apply their knowledge to solve problems [28]. The five problem-solving approaches available to solve problems are the scientific and structured approach, the plug-and-chug approach, the memory-based approach, and the non-obvious approach. Students using scientific and structured approaches are more likely to solve problems than students using unstructured, memory-based, and challenge approaches [29].

Learning media are various tools and means used to convey information from one place to another and create a supportive learning environment so that students can learn well [30]. Learning media are various sources used by teachers to help students learn efficiently, effectively, and accurately. One type of learning media uses information, communication, and technology [31]. Several techniques must be considered to maximize the use of ICT-based media in achieving learning objectives [32]. The University of Colorado developed PhET simulation media for teaching physics [33].

PhET is a collection of moving simulations or interactive animations that allow students to explore and learn actively [34]. By providing interactive simulations, PhET encourages students to learn actively and develop their critical thinking skills [35]. The acceptance of student responses was very high. This result shows that students feel happy and interested in using PhET simulations [36]. Integrating PhET simulation with Inquiry Learning results in more scientific method learning. Students are encouraged to formulate questions, plan experiments, and engage in deep and meaningful learning experiences that enhance their conceptual understanding and problem-solving skills [37].

21st-century education requires learners to respond quickly to learning, have skills and attitudes, and operate and master technology [38]. Representative media that can connect students' knowledge of the real world with subject matter is essential for effective learning. Certain models can also help students make mathematical connections and link their new and old knowledge [39]. The material chosen for the guided inquiry learning model is closely related to science [40]. This model may be an appropriate approach to education as it is more student-focused [41].

Representative media are important for effective learning because they can connect what students know about the real world with the subject matter. Models can also help students make mathematical connections and expand their knowledge [39]. This is supported through pre-research by observation, which shows that the classrooms at SMAN 2 Palangka Raya have been equipped with adequate infrastructure, such as projectors. Students are also allowed to use electronic gadgets and laptops for learning. Results from interviews with teachers in grade XI show that several learning models have been used previously, including problem-based models, discovery learning on vector material in grade XI, cooperative models in grade 5, and cooperative learning models with mind mapping on cardboard media.

The results of interviews with class XI teachers stated that PhET media had been applied in physics learning, but it was still not integrated with learning models, such as the Inquiry Learning Model. During learning, students still pay less attention, such as in kinematics, dynamics, and static fluid material. The use of PhET media itself for the 2024/2025 school year has never been used, as well as the lack of student attention in learning, especially in materials that require more understanding, including kinematics, dynamics, and static fluid. Using various learning models and media, the guided inquiry model is student-centered, and the guided inquiry model allows teachers to help students understand learning better. In addition, the PhET simulation, supported by adequate facilities and equipment, is expected to increase students' enthusiasm for learning and improve their abilities. Recent studies have shown that using a guided inquiry learning model supported by PhET simulations improves students' concept understanding and their critical thinking skills. A study found that PhET simulations in physics learning improved students' concept understanding by 30% compared to conventional learning approaches [42]. Another study showed that PhET simulations with guided inquiry media can help students solve problems with physical materials [43].

Based on these findings, researchers want to know how the guided inquiry model impacts learning using PhET simulation media in static fluid material with the aim of improving students' problem-solving skills. This research is different from previous studies because it combines the guided inquiry model with PhET simulation on static fluid material, which has not been systematically studied before. Therefore, this research not only helps improve the physics learning approach but also provides scientific evidence on how effective it is to combine the guided inquiry model with the PhET simulation to improve students' problem-solving skills. This research can be used by educators to develop a more interactive learning approach. This approach will focus on understanding concepts and strengthening skills necessary for modern life. This research can also serve as a basis for educational policies that support the use of technology in physics learning.

II. Methods

This study was conducted at SMAN 2 Palangka Raya from the academic year 2023/2024. The study used a quantitative approach and included pre-experiment research with a one-group pretest-posttest design. This design aims to measure changes in student learning outcomes before and after treatment. However, this design cannot control outside variables that may affect the results of the study. Therefore, additional grounds or, if possible, an alternative design are required. However, this design has limitations as no control group to compare learning outcomes with other approaches.

There are several limitations to this research design. First, the absence of a control group makes it difficult to determine whether the improvement in learning outcomes can be solely attributed to the treatment provided. Additionally, external factors such as learning motivation and environmental influences may also enhance student performance, but these factors cannot be adequately controlled within this design. Furthermore, testing effects may occur, where students who took the pretest might perform better on the posttest because of the treatment and increased familiarity with the test materials.

Quantitative research is a data collection process that uses strict rules and the truth as it is obtained [44]. This study involved grade XI students in classrooms 1 to 5 in the odd semester of the 2023/2024 school year at SMAN 2 Palangka Raya. Table 1 shows the population distribution.

Table 1. Population

Class	Quantity
XI-1	43 Student
XI-2	43 Student
XI-3	43 Student
XI-4	43 Student
XI-5	49 Student

This research required subjects with specific characteristics that aligned with implementing the guided inquiry model using PhET simulations. A purposive sampling method was employed to meet the research objectives. The selected sample consisted of Grade XI students who had already learned the basic concepts of physics, particularly static fluid, providing them with the foundational knowledge needed to engage with the material through a guided inquiry approach. The class also represented a diverse academic background, which helped reflect the broader student population and allowed for a more objective assessment of improvements in problem-solving skills. Moreover, the physics teacher recommended the class based on the students' suitability for inquiry-based learning. Lastly, the students had access to the necessary learning tools to support the use of PhET simulations, both in school and at home. The number of students in the class meets the minimum criteria for valid statistical analysis, which is more than 30 students, so that the research results are more representative.

Based on the above criteria, class XI-2, consisting of 43 students, was selected as the experimental class. This selection was based on the recommendation of the physics teacher, who stated that the students in the class had heterogeneous academic abilities, were active in inquiry-based learning, and had access to the technology required for the use of PhET simulations. The choice of class XI-2 as the experimental class was based on the physics teacher's suggestion, the suitability of the students with the inquiry-based learning model, and the equality of students' initial abilities based on the initial observation results. The independent variable of this study is the Guided Inquiry model used by PhET Simulation Media. The dependent variable is the ability of high school students to complete the initial and final tests with the same instrument. Table 2 shows the simple research design.

Table 2. Research design one-group pretest-posttest

Class	Pretest	Treatment	Posttest
Experiment Class	O_1	X	O_2

X refers to the treatment using learner worksheets based on a guided inquiry learning model through PhET simulation media in the experimental class. O_1 represents the pretest scores of the experimental class, while O_2 represents the posttest scores.

The data collection methods used were validation, observation, and tests. For validation, calculations were made based on the validity of the instrument. The instruments used were first tested by experts. This study used tests before and after the research material was given in class. Reliability, differentiating power, and difficulty level of the questions were used to measure this test. In addition, the t-test was used to draw conclusions about the proposed formulation. Table 3 shows the validation criteria to determine the instrument's feasibility.

Table 3. Expert validation criteria

Score	Description
0.8 – 1.0	Very Feasible
0.5 – 0.7	Feasible
0 – 0.4	Not Feasible

Based on the criteria in Table 3, Table 4 shows the results of expert validation of the feasibility of learning devices, namely the Guided Inquiry Model using PhET simulation media, learner worksheets, and problem-solving questions.

Table 4. Instrument validation results

Instrument	Score	Description
Guided inquiry learning module using PhET simulation media	0.95	Very Feasible
Learner worksheets	0.97	Very Feasible
Problem Solving Questions	0.94	Very Feasible

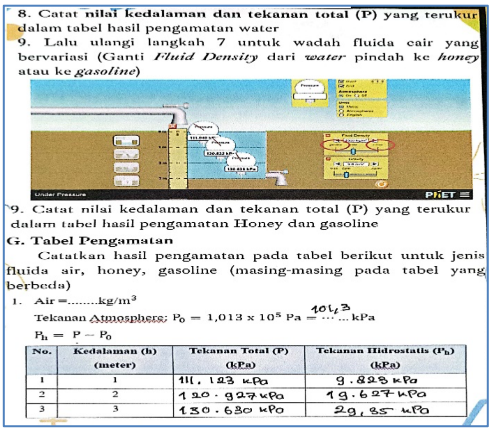
After the instrument was approved, the research was conducted for five meetings. The findings from the problem-solving ability test are the main focus of this study. 1) Conducting a test of problem-solving ability test questions, 2) Processing the test data to assess the validity, reliability, and distinguishing power of the questions, and 3) identifying questions that can be used in the test are steps in the process of collecting data on the problem-solving ability test. The results of the calculation process of test questions using Excel show data from 15 questions given to students. The validity test has six valid questions; the differentiator test has five questions that can be used directly, and one revised question; five valid and unrevised questions are used in the test. The invalid questions were numbers 2, 3, 4, 5, 7, 10, 11, 12, and 14. The pilot test results showed that the five valid questions represented each of the problem-solving ability criteria, with an R value of 0.57 and an R table of 0.3. Thus, the five questions are considered reliable. The pilot test results, which included five descriptive questions assessed through the problem-solving ability assessment rubric, produced problem-solving ability data. The research data were analyzed using the N-gain score and a paired t-test to evaluate the improvement of students' problem-solving skills.

Before the paired t-test is conducted, a data normality test using Shapiro-Wilk is conducted to ensure that the data is normally distributed. If the data is not normally distributed, the analysis will be carried out using the Wilcoxon signed rank test as an alternative. A paired t-test was used to identify significant differences between pretest and posttest scores. N-gain Calculation is used to evaluate the success rate of improving student understanding. N-gain values above 0.7 indicate improvement, N-gain values 0.3 - 0.7 indicate moderate improvement, and N-gain values below 0.3 indicate low improvement. The results of the paired t-tests and the N-gain value will be the basis for making conclusions about how effective the questioning model guided by PhET simulation is in improving problem-solving skills. The improvement of problem-solving ability will be seen from the paired t-test statistical test using the SPSS version 27 program. The analysis of improvement uses N-gain on the pretest-posttest score.

III. Results and discussion

To determine whether the guided inquiry learning model with PhET simulation media can improve students' ability to solve physical problems, pretest and posttest scores were used. Five questions were given to students to collect data on problem-solving ability. The feasibility was assessed. The assessment results showed that students' problem-solving ability was different in both pretests given before treatment using the guided inquiry learning model with PhET simulation media and after treatment with the same model. The learning process in the classroom using the guided inquiry learning model with PhET simulation is depicted in Figure 1.

(a)



8. Catat nilai kedalaman dan tekanan total (P) yang terukur dalam tabel hasil pengamatan water
9. Lalu ulangi langkah 7 untuk wadah fluida cair yang bervariasi (Ganti *Fluid Density* dari *water* pindah ke *honey* atau ke *gasoline*)

9. Catat nilai kedalaman dan tekanan total (P) yang terukur dalam tabel hasil pengamatan Honey dan gasoline

G. Tabel Pengamatan

Catatkan hasil pengamatan pada tabel berikut untuk jenis fluida air, honey, gasoline (masing-masing pada tabel yang berbeda)

1. Air =........kg/m³

Tekanan Atmosphere: $P_0 = 1{,}013 \times 10^5$ Pa = 101,3 kPa

$P_h = P - P_0$

No.	Kedalaman (h) (meter)	Tekanan Total (P) (kPa)	Tekanan Hidrostatis (P_h) (kPa)
1	1	111,123 kPa	9.828 kPa
2	2	120.927 kPa	19.627 kPa
3	3	130.630 kPo	29,35 kPa

(b)

Figure 1. The learning process in the classroom

On the pretest, students obtained an average score of 41.51; on the posttest, they obtained an average score of 64.67. To determine whether students' problem-solving skills have improved, the gain and N-gain values must also be calculated in addition to the pretest and posttest scores. Guided inquiry model learning using PhET simulation media effectively improves students' problem-solving skills. The results show an increase in student scores of 21.25 and a gain in N value of 0.37. This shows that students have better problem-solving skills. Table 5 shows the results of the analysis of students' problem-solving ability in this study, which consists of five indicators.

Table 5. Average pretest and posttest

Class	N	Minimum	Maximum	Mean	Std. Deviation
N-gain	43	0.02	0.79	0.37	0.22
Posttest	43	40	88	64.67	13.90
Pretest	43	16	68	41.51	11.78
Gain	43	1.00	50.00	21.26	13.05

Problem-solving ability improved with an average score of 41.51 on the pretest and 64.67 on the posttest, as shown in Table 5. The authors used a t-test to confirm that students' problem-solving skills improved after using PhET simulation media and a guided inquiry learning paradigm. The data must be regularly distributed in order to be used with the t-test. The normality of the pretest and posttest data was tested with SPSS version 27, and the results are shown in Table 6.

Table 6. Normality test results of students' problem-solving ability

	Kolmogorof - Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pretest	0.161	43	0.007	0.951	43	0.062
Posttest	0.121	43	0.123	0.953	43	0.078

Table 6 shows that the pretest significance value is 0.062 > 0.05, which indicates that the values are regularly distributed. Meanwhile, the posttest significance value of 0.78 indicates that the values are regularly distributed. A paired t-test was used to determine whether the guided inquiry learning approach using PhET simulation media impacted students' ability to solve problems.

The results of the paired t-test are shown in Table 7. The existence of a significant difference between the initial variable and the final variable is indicated by the significance value of 0.001, below 0.05. The fact that Ha is accepted and Ho is rejected indicates a significant treatment effect. As shown in Table 7, students' problem-solving skills are strongly influenced by the syntax in the guided inquiry learning paradigm based on PhET simulation media. The results of hypothesis testing for pretest and posttest t-test data show that the calculated t value is greater than This indicates that when PhET simulation and guided inquiry paradigms are used in the classroom, students' ability to solve problems with static fluid materials is greatly influenced.

Table 7. Problem-solving t-test results

		Paired Samples Test							Significance	
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	One-Sided p	Two-Sided p
					Lower	Upper				
Pair	Pretest-Posttest	23.16	13.36	2.03	27.27	19.04	11.363	43	<. 001	<. 001

Inquiry learning has the space, opportunity, and encouragement to work formally and systematically tested to obtain concrete facts and evidence as done by scientists [45]. According to research [46], the use of PhET media to support guided inquiry model learning is appropriate, effective, and beneficial to improve students' abilities in the field of physical science and their problem-solving abilities. In addition, there is also [43], which shows how the guided inquiry learning paradigm supported by PhET media throughout the 2018-2019 school year impacts the critical thinking and problem-solving skills of physics students in high school. However, this study has a unique contribution compared to previous studies. Different from the studies [43] and [46] which examined the impact of PhET-based guided inquiry learning on basic mechanics concepts, this study focuses on the application of the guided inquiry model with PhET simulation in understanding the concept of static fluid and its impact on improving problem-solving skills. Thus, this study shows that simulation-based learning is effective for mechanics, materials, and static fluid concepts, which can help students solve problems based on the results of hypothesis testing, which is supported by previous research. As mentioned earlier, the results of the problem-solving ability test have improved. Overall, the increase of 43.58% is the highest. Therefore, it can be said that students' problem-solving ability is influenced by the guided inquiry learning approach using PhET simulation media. This is due to the fact that the instructor integrated various elements of problem-solving into the learning process.

This improvement is largely due to the features of the guided inquiry learning model, which allows students to actively learn physics concepts. In this model, the teacher not only passively provides information to students, but also provides questions and tasks that help students find answers. This method is in line with the principle of constructivist learning, which says that students build their own understanding through their interaction with learning materials and their own experiences. The guided inquiry model consists of several steps: orientation, problem formulation, data collection, analysis, and reflection. Each of these steps improves students' problem-solving skills. Students benefit greatly from the PhET simulation as it helps them understand physics concepts better and improves their posttest scores. Here are some of the main ways in which this simulation contributes to the improvement of problem-solving skills. Since students can control their experiments, they are more actively engaged, improving their conceptual understanding and, ultimately, their problem-solving ability.

Although the results of this study show that guided inquiry learning based on PhET simulation is effective in improving students' problem-solving skills, there are some limitations that need to be considered, including:

1. Other factors that influence the results of the study have not been analyzed in depth. Student engagement, teaching quality, and item difficulty may influence the increase in posttest scores. Future research is recommended to include qualitative data, such as classroom observations or interviews, to understand more deeply how student engagement and teaching strategies affect outcomes.
2. The number of questions used in this study was limited. Only five questions were given in the pretest and posttest, which may not be enough to thoroughly reflect the variation of students' problem-solving ability. Further studies can use more diverse instruments with a wider range of concepts to increase the validity of the results.
3. This study only focuses on the concept of static fluid. While previous studies have shown the effectiveness of PhET-based guided inquiry in basic mechanics, this study contributes by showing its effectiveness in static fluid. However, further research is needed to test its applicability to other physics topics, such as electricity, magnetism, or thermodynamics.
4. The research period was relatively short. This study only measured improvement in one learning cycle. Longer-term research is needed to see if the improvement in problem-solving skills can be sustained over a longer period of time and if there is a follow-up effect on students' understanding of other concepts.

Nonetheless, some external factors, such as student engagement and teaching strategies, may be aspects that need to be taken into account in future research. By expanding the scope of material, increasing the variety of questions, and conducting long-term research, the effectiveness of this model can be further tested for various physics concepts and various levels of student understanding.

IV. Conclusions

This study shows that students' problem-solving skills improve with the guided inquiry learning model using PhET simulation media. Although there were variations in results between the initial and final tests, the data showed an increase in a deeper understanding of the concept of static fluid after the learning process. Implementing this learning model proved to be very successful in the classroom, with the research instruments showing excellent feasibility levels. Each school involved in the study showed substantial improvements in problem-solving skills, although each had different characteristics and responses to the learning model. Students could see and understand abstract concepts in static fluid material with the help of PhET simulation media, which proved to be an efficient tool to aid the learning process. Combining PhET simulation with the guided inquiry approach results in a learning environment that encourages the development of problem-solving skills.

This study has several limitations that need to be considered, among others: Individual student factors were not analyzed in depth in the research, limited to one physics concept (static fluid), short research duration, limited evaluation instruments, and is limited to one school only. Future research should explore individual student factors more deeply by incorporating motivational surveys or interviews better to understand the psychological and academic influences on learning outcomes. Additionally, the effectiveness of the guided inquiry model using PhET simulations could be tested on other physics topics, such as rotational dynamics or electromagnetism, to determine whether similar improvements can be observed. Long-term studies are also encouraged, particularly those that assess students' retention of understanding several weeks or months after instruction. Furthermore, developing more comprehensive evaluation instruments, such as incorporating case-based questions or open-ended problem-solving tasks, could provide deeper insights into students' critical thinking skills.

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