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STUDY OF SCIENTIFIC REASONING AND CONCEPT MASTERY OF STUDENTS THROUGH GUIDED INQUIRY LEARNING MODEL ASSISTED BY FORMATIVE ASSESSMENT

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ABSTRACT

This study endeavors to assess the impact of guided inquiry learning, complemented by formative assessment, on students' scientific reasoning (SR) and concept mastery (CM). The research involved 20 students from class XI A at SMA Muhammadiyah 02 Sumberpucung, utilizing questions adapted from the modified Lawson classroom test of scientific reasoning (MLCTSR) to measure SR, and the force concept inventory (FCI) to gauge CM. The instructional focus was Newton's law of motion. Both qualitative and quantitative analyses were employed for data interpretation. The findings revealed a substantial influence of the guided inquiry learning model on SR, with a *d*-effect size value of 3.829. Similarly, students' CM exhibited a noteworthy impact, evidenced by a d-effect size value of 3.099. These values signify that both SR and CM fall within the category of greater than the standard effect size. The outcomes imply a significant enhancement in students' proficiency in both SR and CM as a result of the guided inquiry learning approach.

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INTRODUCTION

Proficiency in skills is crucial due to the rapid advancements in science and technology. In today's society, it's essential for everyone to have a comprehensive understanding of science, given its importance in the professional world. The modern workplace demands high-quality human resources, emphasizing critical thinking and logical reasoning (Puspita, 2016). As a result, teachers must grasp the 21st-century learning paradigm, which suggests that students shouldn't only focus on subject-specific knowledge. Instead, they should develop a range of skills using various forms of reasoning tailored to the needs of the 21st century. Essentially, education needs to evolve to equip students with a well-rounded skill set that goes beyond traditional subjects, aligning with the dynamic demands of the modern professional landscape.

Scientific reasoning (SR) involves a set of skills essential for modifying natural and social concepts or theories through research, experimentation, evaluation of evidence, and formulating conclusions and arguments supporting the findings (Khoirina& Cari, 2018). Proficiency in problem identification (PI) is crucial for enhancing critical thinking and problem-solving abilities. It allows individuals to scientifically explain natural phenomena through a robust understanding (Docktor & Mestre, 2014).

Concept mastery (CM) is equally vital for students, aiding their comprehension of ideas in line with scientists' understanding. Proficiency in CM is demonstrated by the ability to grasp and apply scientific theories to phenomena. For example, understanding Newton's laws of motion empowers students to explain various natural occurrences, including object motion, gravitational forces, and celestial dynamics (Dawson et al., 2016; Nojiri & Odintsov, 2007). In this context, CM is defined as students' capacity to comprehend a phenomenon both theoretically and in its practical application. Studies affirm that robust CM not only aids in understanding but also contributes to problem-solving skills related to natural phenomena (Dawson et al., 2016).

However, it's noteworthy that various studies have identified prevalent misconceptions among students in Indonesia, as evidenced by Tayubi (2005) and Efendi (2011). These misconceptions highlight the importance of targeted educational interventions to enhance concept mastery among students, ensuring a more accurate and comprehensive understanding of scientific principles.

Acknowledging the existing challenges in students' SR and CM, a viable solution is proposed through the implementation of inquiry learning. This science learning model is expressly oriented towards the scientific method, with the aim of enhancing students' SR. The depth of knowledge gained through inquiry learning is anticipated to bolster students' reasoning skills, particularly in the critical evaluation of investigation results (Daryanti et al., 2015; Karmila et al., 2019).

However, it is imperative to recognize that the efficacy of the inquiry learning model, though promising, often encounters practical challenges. The inquiry learning process poses difficulties for students, presenting a substantial hurdle. Notably, many students struggle with problem identification, hypothesis formulation, and integrating evidence or data with their existing knowledge and hypotheses. These challenges underscore the necessity for a comprehensive solution that supports the effective implementation of inquiry learning methodologies. Addressing these obstacles is essential to optimize the potential benefits of this pedagogical approach and ensure that students not only engage with inquiry learning effectively but also develop robust SR and CM in the process. As such, ongoing efforts should be directed towards refining and supplementing the inquiry learning model to provide targeted support for students facing these specific challenges.

Formative assessment, as elucidated by Black and Wiliam (2009), serves as feedback aimed at gauging students' learning progress and informing subsequent instructional strategies. Integral to classroom participation, formative assessment is anticipated to enhance students' SR and CM, particularly in complex subjects such as Newton's laws of motion. By actively involving students in the learning process, formative assessment contributes to a more nuanced understanding and application of scientific concepts.

In the educational context, the synergy between guided inquiry learning and formative assessment is poised for analysis, focusing on the evolution of students' SR and CM. Prior studies, exemplified by Sundari and Rimadani (2020), have showcased improved CM and SR outcomes among students employing scaffolding strategies. Additionally, Shilla (2018) investigated the application of Newton's laws and SR rationality in physics education, shedding light on the impact of different learning models.

However, identified weaknesses in past research, particularly the dearth of teacher feedback and limited attention to students' challenges, underscore the importance of addressing these aspects. This study endeavors to mitigate these limitations by placing increased emphasis on understanding students' difficulties and providing more frequent and constructive feedback. The intent is to enhance the effectiveness of the guided inquiry learning model, assisted by formative assessment, in augmenting students' SR and CM in the intricate domain of Newton's laws of motion. Through a meticulous examination of these intertwined pedagogical elements, this research seeks to contribute valuable insights for refining educational practices and optimizing student learning outcomes.

METHOD

This research adopts a mixed-method approach with an embedded-experiment design, combining quantitative and qualitative methodologies concurrently (Creswell & Sinley, 2017). The study focuses on 20 students from class XI A at SMA Muhammadiyah 02 Sumberpucung and transpires from March to April 2023. The assessment tools employed include a problem identification (PI) test, modified from the modified Lawson classroom test of scientific reasoning (MLCTSR) with five questions, and a concept mastery (CM) test using the force concept inventory (FCI) comprising 15 questions, developed by Hestenes et al. (1992).

Quantitative analysis is undertaken to ascertain the impact of the guided inquiry learning model, supported by formative assessment, on students' SR and CM concerning Newton's laws. Pretest and posttest data are collected and subjected to normality testing. The paired sample t-test is employed for normally distributed data, while the Wilcoxon test is utilized for non-normally distributed data. Subsequently, the effect size test measures the influence of the learning strategies on the dependent variables, with Cohen's descriptors employed for interpretation.

Table 1 is employed to present the calculated results and their interpretation. This comprehensive mixed-method design endeavors to provide a nuanced understanding of the impact of the guided inquiry learning model, complemented by formative assessment, on students' SR and CM in the context of Newton's laws, thereby contributing valuable insights to the existing body of educational research.

Table 1. Interpretation of Cohen's value.

Value of *d*-effect size	Category
$d > 1.000$	Larger than standard
$0.510 \leq d \leq 1.000$	Greater than standard
$0.210 \leq d \leq 0.500$	Standard
$d \leq 0.200$	Smaller than standard

Table 2. Interpretation of N-Gain mean value.

Value *g*	Category
$g < 0.250$	Low
$0.250 \leq g < 0.450$	Lower-medium
$0.450 \leq g < 0.650$	Upper-medium
$g \geq 0.650$	High

Upon obtaining the pretest and posttest scores, the assessment of students' improvement in SR and CM is conducted through the calculation of N-gain. This method aims to discern the disparity between pretest and posttest scores subsequent to the completion of the learning process (Waldrip et al., 2014). The N-gain interpretation is elucidated in Table 2, providing a systematic framework for evaluating the magnitude and significance of the observed changes in students' SR and CM. This quantitative measure serves as a valuable indicator to gauge the effectiveness of the guided inquiry learning model assisted by formative assessment in facilitating the enhancement of students' SR and CM, particularly within the context of Newton's laws. The N-gain values will furnish insights into the degree of improvement attained by students, thereby contributing to a comprehensive assessment of the instructional approach's impact on the targeted cognitive domains.

RESULTS

The examination of pretest and posttest scores from 20 students in class XI A at SMA Muhammadiyah 02 Sumberpucung reveals noteworthy findings regarding scientific reasoning (SR) and concept mastery (CM). The SR pretest score, averaging 1.550, situates students within the low SR category. Subsequent to the intervention, the posttest average score rises to 4.150, indicating a shift to the medium SR category. Similarly, the CM pretest score, averaging 1.700, initially categorizes students in the low CM bracket. However, the posttest CM score registers an improvement to 4.050, placing students in the sufficient or moderate CM category.

Following the computation of average scores, a Smirnov Kolmogorov test is employed to assess the normality of SR and CM data. The test results indicate non-normal distribution, prompting the utilization of the Wilcoxon test for the subsequent difference analysis. The outcomes of this test are elucidated in detail in Table 3, providing a comprehensive understanding of the statistical significance of observed changes in SR and CM scores before and after the guided inquiry learning model assisted by formative assessment. These results contribute valuable insights into the effectiveness of the instructional approach in fostering improvements in students' SR and CM within the context of Newton's laws.

The descriptive analysis of students' SR indicates that, among the five questions presented, the highest score achieved by students is 5 (five). Similarly, in CM, with a set of 15 questions, the highest score attained by students is 7 (seven). The Wilcoxon test results in Table 3 reveals a comparative examination of the average values of SR and CM in both pretests and posttests. The pretest average for SR is 1.550, contrasting with the posttest average of 4.150. In parallel, the pretest and posttest averages for CM are 1.700 and 4.050, respectively. This statistical analysis implies a significant difference between students' SR and CM scores before and after the posttest. The elevated posttest averages relative to the pretest averages suggest a notable improvement in both SR and CM among students following the learning process.

To calculate the effect size of the differences observed in SR and CM scores between the pretest and posttest for Newton's laws, Cohen's *d*-effect size is employed. The calculations for SR and CM effect sizes are outlined in Equation 1 and Equation 2, respectively. The utilization of effect sizes provides a standardized metric to quantify the magnitude of the observed changes, allowing for a more nuanced interpretation of the practical significance of the learning intervention.

$$d = \frac{M_a - M_b}{SD_{gab}} = \frac{4.150 - 1.550}{0.679} = 3.829 \quad (1)$$

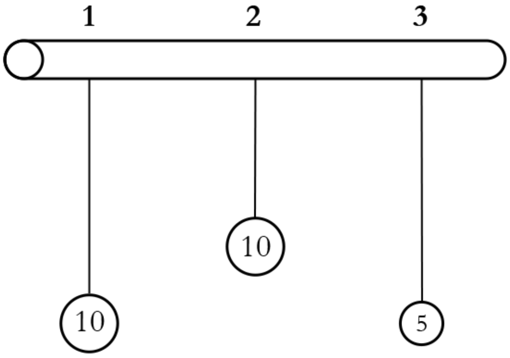
$$d = \frac{M_a - M_b}{SD_{gab}} = \frac{4.050 - 1.700}{0.781} = 3.009 \quad (2)$$

The calculated effect size of 3.829 for SR and 3.009 for CM reveals a substantial impact of the guided inquiry learning model, assisted by formative assessment, on students' cognitive outcomes related to Newton's laws. These effect sizes categorize the influence as greater than the standard, indicating a very strong effect on both SR and CM.

Additionally, the N-gain values further substantiate the positive impact of the learning intervention. With an N-gain value of 0.754 for SR, the pretest to posttest improvement is categorized as high. For CM, the N-gain value of 0.443 suggests a lower-medium category of improvement. These values underscore the effectiveness of the guided inquiry learning model in fostering notable advancements in students' SR and moderate improvements in CM.

Table 3. Wilcoxon test results of scientific reasoning and concept mastery.

Ability	Group	Mean	Std. Deviation	Statistical z	*p value*
Scientific reasoning	Pretest	1.550	0.604	-3.959	< 0.001
	Posttest	4.150	0.745		
Concept mastery	Pretest	1.700	0.656	-3.958	< 0.001
	Posttest	4.050	0.887		



In the illustration, three ropes are suspended from a rod. Ropes 1 and 3 share identical lengths, while rope 2 is shorter. Each rope terminates with a load attached. A load of 10 weight units is affixed to ropes 1 and 2, while a load of 5 weight units is attached to rope 3. The ropes, once laden with weights, can be oscillated forward and backward, and the oscillation time can be calculated.

If you want to determine whether the length of the rope affects the forward and backward oscillation time, which rope(s) would you use?

a. Only rope 1
b. All ropes
c. Ropes 2 and 3
d. Ropes 1 and 2

Reasons:

1. We should use the longest rope.
2. We should compare ropes with both light and heavy loads.
3. Only a rope with different length but equal mass is needed.
4. To create all possible comparisons.

Figure 1. Scientific reasoning question number 2.

Table 4. Reasons for students' answers on reasoning question number 2.

		Student 1	Student 2
Pretest	Answer :	D, C	D, C
	Reason :	Because what is needed is a rope of different lengths.	Just answer.
Posttest	Answer :	D, B	C, B
	Reason :	Because what must be compared are ropes that have unequal weight.	Because you have to compare ropes that have different masses.

A large truck breaks down on the road and subsequently receives a push from a smaller car, as depicted in the image. While the car imparts a thrust to the truck, the car experiences an increase in speed. Therefore, the condition occurring while the car pushes the truck is….

a. The amount of force the car imparts to push the truck is equal to the amount of force the truck imparts to the car
b. The amount of force the car imparts to push the truck is smaller than the amount of force the truck imparts to the car
c. The amount of force the car imparts to push the truck is greater than the amount of force the truck imparts to the car
d. The truck is propelled by the car's engine
e. Both the car and the truck do not utilize force. Instead, they rely on the car's engine.

Figure 2. Concept mastery question number 6.

Table 5. Reasons for students' answers on concept mastery questions.

		Student 1	Student 2
Pretest	Answer :	A	A
	Reason :	Because both trucks and cars exert the same force.	Because both have the same amount of force
Posttest	Answer :	D	C
	Reason :	Because at that time it was the car engine that had the power to push the truck.	Because the truck broke down and could not move.

DISCUSSION

The findings of the study revealed a discernible impact on scientific reasoning (SR) and conceptual mastery (CM) within the cohort of 20 students from class XI A at SMA Muhammadiyah 02 Sumberpucung, attributable to the implementation of the guided inquiry learning model coupled with formative assessment. The efficacy of this pedagogical approach in enhancing SR and CM is delineated within the upper medium and lower medium strata. Previous research corroborates the salutary effects of the guided inquiry learning model on augmenting students' comprehension of SR, as evidenced by studies conducted by Kurniawati and Diantoro (2014) and Loverude et al. (2011), highlighting the comparative effectiveness of inquiry learning over conventional methods. Similarly, CM exhibits improvement through guided inquiry learning, as indicated by research conducted by Handhika (2010), Suma (2010), and Wijayanti and Hindarto (2010).

The investigation underscores the palpable advancements in students' SR subsequent to engaging in SR research. The heightened SR is attributed to the adoption of the practicum method, rendering the learning process more accessible and comprehensible. Furthermore, the augmentation in CM extends beyond mere conceptual understanding, encompassing the students' capacity to interlink concepts across diverse situations.

The incorporation of formative assessment emerges as a pivotal strategy for enhancing the learning trajectory, given its discernible impact on fortifying both SR and CM among students. Consequently, the research was meticulously designed with a thematic focus on SR and CM, centered on the domain of Newton's law of motion (Marsandi et al., 2016). This deliberate thematic alignment underscores the commitment to probing and elucidating the multifaceted dimensions of students' cognitive development within the ambit of scientific reasoning and conceptual mastery.

The analysis of each question indicator has revealed that students exhibit low to medium levels of SR and CM. Remarkably, while scores for other indicators demonstrated an overall increase, SR and CM levels remained relatively stagnant. This observation is underscored by the meticulous examination of score analyses for each question indicator, prompting an exploration of those areas where scores have diminished. The ensuing discussion delves into the specific question indicators that witnessed score reductions, elucidating the underlying rationales provided by students.

Controlling Variables (Variables Affecting the Pendulum)

In addressing scientific reasoning question number 2 (Figure 1), it was observed during the post-test that students predominantly selected answers (D, B) and (C, B) (Table 4). This suggests a prevailing notion among students that in determining the influence of rope length on pendulum oscillation time, ropes 1 and 2 must be utilized, with one student opting for ropes 2 and 3. Notably, while students accurately responded to this question during the pretest, a discernible conceptual error emerged during the post-test. This discrepancy points to a misconception held by students, emphasizing the need for targeted intervention to rectify these cognitive distortions.

Forces That Act Continuously

Evaluation of the concept mastery question number 6 (Figure 2) illuminates students' selections for observer D and C (Table 5). This choice implies a belief among students that the car engine and the force applied by the car to propel the truck surpass the force exerted by the truck itself. Consequently, it is deduced that students grapple with misconceptions or misunderstandings pertaining to the mastery of the concept indicator number 6. This discrepancy underscores the imperative for pedagogical strategies aimed at dispelling these conceptual ambiguities and fostering a more accurate understanding among students.

The identified misconceptions among students, as highlighted by the aforementioned question indicators, underscore the need for targeted interventions to rectify conceptual inaccuracies stemming from potential misinterpretations. Acknowledging the pivotal role of meaningful learning in addressing and overcoming these misconceptions, it becomes imperative for teachers to adopt pedagogical approaches that facilitate a deep and enduring understanding of the subject matter.

In the context of teaching physics problem-solving skills, fostering meaningful learning becomes paramount. The cultivation of students' reasoning skills and mastery of concepts proves indispensable in navigating the complexities of problem-solving. As facilitators of this learning process, teachers assume a critical role, necessitating a heightened focus on providing constructive feedback and affording students ample opportunities to articulate their ideas and opinions.

Furthermore, the dynamic nature of the learning process demands creativity on the part of the teacher, particularly in making the educational experience more engaging and captivating. Incorporating quizzes and questions that pique students' interest not only sustains their attention but also serves as a mechanism for reinforcing comprehension.

This pedagogical perspective aligns with the findings of Sundari and Rimadani (2020), who observed that active student involvement in idea construction significantly enhances both SR and CM. Additionally, the research conducted by Johnson and Mayer (2009) posits that students leveraging interactive media exhibit superior learning outcomes compared to their counterparts in conventional classrooms. Consequently, the guided inquiry model, when complemented by interactive media, emerges as a potent approach with the potential to elevate students' grasp of physics concepts beyond what traditional methods can achieve. As such, teachers are encouraged to embrace innovative teaching strategies that leverage active student engagement and technological tools to optimize the learning experience and mitigate misconceptions effectively.

It can be inferred that the instructional approach significantly enhances students' SR and CM, signifying the efficacy of the guided inquiry learning model in promoting a robust understanding of Newton's laws. Furthermore, the researcher's analysis of students' answers reveals a focus on understanding the reasons behind the decrease in scores. Specifically, attention is directed towards students who provided correct answers in the pretest but exhibited incorrect responses in the posttest. This analytical approach aims to identify areas of challenge or misunderstanding among students, providing valuable insights for refining instructional strategies and addressing specific learning needs. In summation, the combined findings affirm the significant positive impact of the guided inquiry learning model with formative assessment on students' SR and CM related to Newton's laws.

CONCLUSION

In light of the research findings and subsequent discussion, a conclusive inference can be drawn that the implementation of the guided inquiry learning model, coupled with formative assessment, yields a positive impact on studentss scientific reasoning (SR) and conceptual mastery (CM). The overall trend across SR and CM indicators indicates improvement, demonstrating a positive trajectory in students' cognitive development. However, it is noteworthy that a nuanced analysis reveals a decrease in two specific indicators: those pertaining to the control of SR variables and the consistent application of styles for CM. The discernible enhancement in students' cognitive levels, although overall positive, did not reach a statistically significant level. This nuanced outcome can be attributed to the unfamiliarity of most students with the concept mastery, compounded by the perceived difficulty of the modified Lawson's classroom test of scientific reasoning (MLCTSR) and the force concept inventory (FCI), as indicated by the challenging nature of these assessments during the field test. This comprehensive evaluation underscores the nuanced nature of the observed improvements, emphasizing the need for ongoing pedagogical refinement and targeted interventions to address specific challenges encountered by students. Additionally, future endeavors may benefit from strategies aimed at enhancing students' familiarity with complex concepts and optimizing the difficulty levels of assessments to ensure a more accurate reflection of cognitive development.

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AUTHOR CONTRIBUTIONS

Each author participated in the conception and design of the study, data collection, analysis, interpretation, writing, and revision of the manuscript. The final version of the manuscript was approved by all authors.

CONFLICT OF INTEREST STATEMENT

The authors declare that they do not have any conflicting interests concerning the research, writing, and publication of this paper.

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