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Profiles and Error Patterns of Senior High School Students' Scientific Reasoning on Static Fluid Topics: An Empirical Analysis

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Abstract: This study aims to analyze the profiles and error patterns in the scientific reasoning of upper secondary school students regarding static fluids. This study employs a quantitative approach using a survey design. The study involved 84 students in Malang as respondents, selected through purposive sampling based on the following criteria: having studied static fluids, being taught by the same physics teacher, being enrolled in an active physics specialization class, and being present for the full duration of the test. The test instrument consisted of 10 open-ended questions covering five indicators of scientific reasoning, namely correlational reasoning, proportional reasoning, probabilistic reasoning, control of variables, and hypothetical-deductive reasoning, with a Cronbach's alpha reliability coefficient of 0.812. The reliability of the instrument and the inter-rater agreement were evaluated through a two-stage inter-rater test using Cohen's Kappa and the Intraclass Correlation Coefficient (ICC), which yielded an ICC value of 0.981 (very high category). Data analysis was conducted in two stages: quantitatively to measure the level of scientific reasoning, and qualitatively through content analysis to identify patterns of students' errors. The research shows that students' average scientific reasoning ability falls within the moderate category (49.42), with the distribution of cognitive levels dominated by the Late Transition (37%) and Early Transition (35%) stages. Only 12% of students reached the Formal Operational level. Proportional reasoning indicators showed the highest achievement, whilst hypothetical-deductive reasoning was the lowest. The highest conceptual understanding was found in Pascal's Law, followed by Archimedes' Principle, and the lowest in hydrostatic pressure. The main error patterns identified were students' difficulty integrating quantitative data into numerical probabilities and their inability to design systematic experiments and identify control variables. These findings indicate that although students passively understand basic concepts, they still struggle with logical justification and procedural reasoning.

Keywords: error patterns, scientific reasoning, static fluid.

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INTRODUCTION

Scientific reasoning can be regarded as a complex cognitive process that involves formulating hypotheses, collecting data, and selecting evidence to support a particular conclusion (Lawson, 2010). Scientific reasoning comprises probabilistic reasoning, proportional reasoning, control of variables, correlational reasoning, observational reasoning, hypothetical-deductive reasoning, and combinatorial reasoning (Bao et al., 2018; Lawson, 2004). These skills form a crucial foundation for gaining a better scientific understanding and solving problems using scientific applications and data analysis as evidence (Ari et al., 2024; Mayasyafira et al., 2025; Nurjamilah et al., 2020). Several researchers have demonstrated that students with strong scientific reasoning skills can understand subject concepts more deeply and apply their knowledge in various situations (Luo et al., 2021; Pratiwi et al., 2025; Shofiyah et al., 2024). Through scientific reasoning, students not only study science but also use a constructive method to think more critically to solve problems.

It is important to analyze the profiles and error patterns in students' scientific reasoning. This is because the results of such an analysis can help teachers to understand the specific weaknesses in students' scientific thinking (Prastiwi et al., 2018). Through this identification, teachers can recognize that students' errors do not occur randomly but rather follow patterns that can be categorized as common falsehoods in scientific reasoning about physics problems (Erlina, Susantini, & Wasis, 2018). Based on an understanding of students' error patterns, teachers can develop teaching strategies that address deficiencies in scientific reasoning rather than merely repeating content delivery (Erlina, Susantini, Wasis, et al., 2018; Pickal et al., 2023). Without a deep understanding of these error profiles and patterns, teachers risk delivering instruction that is irrelevant to students' actual cognitive needs (Kramer et al., 2021; Soeharto & Csapó, 2021). Understanding patterns of error in students' scientific reasoning is the primary foundation for teachers to systematically and purposefully develop students' scientific thinking skills.

At present, students' levels of scientific reasoning remain relatively low. Several research findings indicate that students' scientific reasoning, overall, still falls within the concrete operational category (Dinata et al., 2025; Ningrum et al., 2024). Students tend to struggle with hypothetical-deductive reasoning; that is, they are able to answer the questions given but find it difficult when asked to provide reasons for their answers (Cahyaningrum, 2019; Kamaluddin et al., 2023). This is because, during classroom instruction, teachers still focus on solving mathematical problems, whilst students merely memorize; consequently, students' views of scientific knowledge become naive, perceiving it as static, fixed, universal, certain, and unchangeable (Abate et al., 2021; Effendy et al., 2018). Not only that, but students' probabilistic thinking and their ability to control variables remain problematic and need improvement (Koes & Putri, 2021).

The same applies to the topic of static fluids. This topic is divided into three subtopics: hydrostatic pressure, Pascal's law, and Archimedes' principle. Students still often find this material difficult. Students often struggle to identify the known variables in a problem and to link mathematical equations to everyday physical phenomena (Fernando et al., 2024; Irawan et al., 2025; Yulianti et al., 2020). Furthermore, students often experience significant difficulties in understanding the concept of hydrostatic pressure, for example, in identifying the behavior of objects, such as floating, hovering, or sinking, because this material is abstract, lacks appropriate visual representations, and is poorly connected to everyday phenomena (Aliyah et al., 2025; Kaharu et al., 2024; Mansyur et al., 2022). The results of several studies indicate that students' problem-solving skills in this subject remain low, with an average score of 48.88, and that there are many misconceptions regarding hydrostatic pressure and surface tension (Aliyah et al., 2025; Putranta & Afifah, 2025; Siahaan et al., 2025). Students also have difficulty understanding Pascal's principle; they continue to believe that pressure will be the same throughout a closed container with different cross-sectional areas (Ringo et al., 2019).

Several previous studies have examined students' scientific reasoning about static fluids, but they still exhibit several limitations. The study conducted by Prastiwi et al. (2018) used a reasoned multiple-choice instrument with a small sample size, thus failing to describe error patterns in depth; Fernando et al. (2024) focused more on classifying Piaget's operational levels without detailing error patterns. Ari et al. (2024), although their sample was larger, remained limited to six questions and did not explicitly integrate the Lawson-Karplus rubric. These studies generally have not provided a comprehensive analysis of error profiles and patterns. Therefore, this study analyses the profiles and patterns of scientific reasoning errors among senior high school students on static fluid material, using the Lawson-Karplus rubric and Piaget's categories, to provide a more detailed diagnosis and address gaps in previous research.

Recognizing the low level of students' scientific reasoning skills, numerous studies have developed and tested various models and learning strategies. Research indicates that students' levels of scientific reasoning tend to be low across various educational levels, but can be significantly improved through a modeling-based learning approach, the selection of media tailored to students' reasoning profiles, and the reinforcement of task-specific self-efficacy (Kusumaningdyah et al., 2024; Malone & Schuchardt, 2023; Nyberg et al., 2022). Most existing research still focuses on developing models or learning strategies, whilst research that thoroughly maps students' scientific reasoning profiles and error patterns, particularly in the context of static fluids, remains very limited (Ari et al., 2024; Fernando et al., 2024).

This study aims to conduct a comprehensive empirical analysis of the profiles and error patterns in the scientific reasoning of upper secondary school students on the topic of static fluids. Unlike previous studies that have placed greater emphasis on the development of learning models, this study specifically aims to identify and classify the most common error patterns made by students in scientific reasoning so that this approach can provide a comprehensive picture of students' difficulties (Atqiya et al., 2021; Dah et al., 2024; Wilujeng & Wibowo, 2021). Analysis results can serve as a basis for developing more effective learning models (Misbah et al., 2020). In addition, the findings will help improve the quality of physics learning at the high school level (Tsaniya et al., 2022).

Given the background, this study focuses on mapping error patterns in the scientific reasoning skills of upper secondary school students during physics lessons, specifically regarding the topic of static fluids. Therefore, this study is designed to answer the following two main questions:

1. What is the profile of upper secondary school students' scientific reasoning skills in relation to the topic of static fluids?
2. What are the most prevalent error patterns exhibited by upper secondary school students in their understanding of the topic of static fluids?

METHOD

This study employed a quantitative approach using a survey research design (Creswell, 2018). This approach was chosen because the study aims to objectively describe students' scientific reasoning abilities and to identify patterns of error in a measurable way. A survey design was used to collect numerical data from the sample via a structured scientific reasoning test instrument on the topic of static fluids. Through this design, the researcher was able to process the data in tabular form, calculate error percentages, and perform statistical analyses to obtain an accurate picture of the students' reasoning abilities.

Participants

Participants in this study were selected using purposive sampling. The sample was restricted to a single state senior high school in Malang, East Java, to maintain contextual homogeneity in school culture and learning facilities. To be included in the study, participants had to meet the following specific inclusion criteria: (1) be Year 12 students who had covered the static fluids curriculum; (2) be under the supervision of the same physics teacher; (3) be from an active physics stream class in the current academic year; and (4) be fully present during the diagnostic test. Based on these criteria, a total of 84 students were selected as the final research sample.

Instruments

Data collection in this study utilized a scientific reasoning test comprising 10 essay-type questions. The content of this test was developed by adopting Lawson's (1978) theory of scientific reasoning, adapted to the characteristics of static fluid physics material. This test focuses on five aspects of Lawson's scientific reasoning, namely: proportional reasoning, control of variables, probabilistic reasoning, correlational reasoning, and hypothetical-deductive reasoning. These ten essay questions were distributed evenly across the three main subtopics of static fluid mechanics, namely hydrostatic pressure, Pascal's law, and Archimedes' principle. The choice of this essay question format was intended to enable the researcher to examine in depth the students' thought processes, written arguments, and the patterns of errors they made when solving physics problems requiring scientific reasoning.

Research Procedure

This research procedure was carried out in stages through three main phases: instrument preparation, data collection, and data analysis. During the preparation phase, the scientific reasoning test on static fluid material was developed and validated by two experts, both senior lecturers in physics education. These two experts were tasked with assessing the suitability of the questions across three main aspects: their relevance to the static fluid mechanics material, the construction of the scientific reasoning questions, and their language use. The assessment was carried out using a validation sheet with a 1-4 Likert scale (1 = Very Unsuitable, 2 = Unsuitable, 3 = Suitable, 4 = Very Suitable). The scores from both validators were then calculated using the Percentage of Agreement technique by dividing the total score obtained by the maximum score, then multiplying by 100%.

Furthermore, the expert validation results indicated two categories of items. In the first category, items that met the content and structural criteria and had an agreement percentage above 75% were deemed valid and did not require revision. However, the second category indicates that some questions still do not meet the criteria and therefore require minor revisions in line with the experts' suggestions and recommendations. Once all questions have been declared valid, both those requiring no revision and those requiring revision, the instrument will then proceed to the next stage, the empirical validation. The empirical validation process is carried out simultaneously, once all questions have been declared valid and revised in accordance with the experts' input.

Moving on to the data collection stage, the validated questions were administered simultaneously to 84 Year 12 students, whose responses served as the primary empirical data for this study. Finally, in the data analysis stage, all the students' collected answers were processed using IBM SPSS. This analysis served two purposes: firstly, to assess the empirical validity and difficulty of the test items; and secondly, to describe the profile of students' scientific reasoning abilities whilst identifying patterns of error in their answers to static fluid mechanics.

Data Analysis

The data analysis in this study combines quantitative and qualitative approaches in sequence. For the quantitative analysis, students' responses were assessed according to a rubric. Responses were categorized using a rubric adapted from Karplus et al. (1980) and Lawson et al. (1984), as shown in Table 1. The students' responses were then processed using IBM SPSS. Descriptive statistics, including the mean, median, standard deviation, and minimum and maximum values, were calculated to characterize the general profile of students' scientific reasoning abilities. The results of the analysis also demonstrated the instrument's empirical quality, with an á reliability of 0.812, a discrimination index of 0.497, and a difficulty index of 0.495. In addition, item validity was assessed by examining the p-value, with items deemed valid if the p-value was below 0.05 ($p < 0.05$).

The content analysis procedure was carried out in a step-by-step, systematic manner. Firstly, the students' answers were assessed quantitatively using a scoring rubric based on scientific reasoning criteria (scores from 0 to 4) in accordance with Table 1. This assessment aimed to provide an overview of the distribution and percentage of occurrence for each score category. Secondly, to qualitatively identify patterns of errors, the researcher conducted data reduction by sorting the assessment results into subtopics of static fluid mechanics: hydrostatic pressure, Pascal's Law, and Archimedes' Principle. The qualitative analysis was then focused solely on the score groups that occurred most frequently within each subtopic. Thirdly, for test items where the dominant score group was not optimal, namely, less than 4 for correlational, proportional, control of variables, and hypothetical-deductive reasoning, and less than 3 for probabilistic reasoning, these were re-examined by noting the specific forms of error in the students' answers. These errors took the form of an inability to provide logical reasoning, mathematical conversion errors, failure to identify variables and design an experiment, and a tendency to answer questions in qualitative rather than quantitative terms. Meanwhile, for items with a dominant score group of up to 4, the analysis focused on the characteristics of conceptual mastery and the accuracy of students' lines of reasoning. Fourthly, the uniform error types from the score groups below the maximum were synthesized into a description of error patterns, whilst for the score group of 4, these were formulated as patterns of conceptual mastery in relation to the relevant scientific reasoning indicators. The student response excerpts presented in the research results table were selected through purposive sampling from the answer sheets of students in these dominant score groups. This selection was made because these samples were considered the most representative for illustrating common misconceptions and the characteristics of most students' thinking patterns regarding the relevant scientific reasoning indicators. Consequently, the researchers compiled an in-depth, context-specific description of error patterns for each sub-topic of static fluid mechanics.

The results of the instrument validation analysis show that all scientific reasoning indicators met the validity criteria. Firstly, the Correlational Reasoning indicators in questions 1 and 2 had Pearson correlation coefficients of 0.49 and 0.53, respectively. Secondly, the Proportional Reasoning indicators in questions 3 and 6 had correlation coefficients of 0.38 and 0.74, respectively. Thirdly, the Control of Variables indicators in questions 4 and 8 had correlation coefficients of 0.66 and 0.70. Fourthly, the Probabilistic Reasoning indicators in questions 5 and 9 had correlation coefficients of 0.63 and 0.64. Finally, the Hypothetical Deductive Reasoning indicators for questions 7 and 10 have correlation coefficients of 0.60 and 0.69. All indicators show a significance value of 0.000, meaning that all test items are deemed valid.

Moreover, this study conducted an inter-rater reliability test to assess the level of agreement among assessors. This test was carried out by two experts using a representative sample of 30 student answer sheets (35.7% of the total sample). The sample comprised three categories, low, medium, and high, with 10 answer sheets selected from each category. The test was conducted to enhance the objectivity and reliability of the assessment. The inter-rater reliability analysis was carried out at two levels. At the item level, Cohen's Kappa was used based on a 0–4 scoring rubric. Meanwhile, for students' total scores on a 0–100 scale, the Intraclass Correlation Coefficient (ICC) was used. The results of the inter-rater reliability analysis showed that the Cohen's Kappa values for the ten questions ranged from 0.688 to 1.00. Based on the criteria set out in Landis & Koch (1977), all Kappa values fell within the 'good' to 'very good' categories. Meanwhile, the ICC result was 0.981, which falls within the 'very good' category (Koo & Li, 2016).

Table 1. Rubric of scientific reasoning indicator

Scientific Reasoning Indicators	Score	Student Answer Criteria
Correlational Reasoning	4	The explanation is accurate and successfully links all aspects of the problem.
	3	The explanation is accurate, but it only links one aspect of the problem.
	2	Explains, but it is not relevant to the problem.
	1	The explanation is illogical, based on a misunderstanding, or nonexistent.
	0	No answer provided.
Proportional Reasoning	4	The answer is correct with accurate ratio/conversion calculations.
	3	The answer is correct, but the ratio calculations are inaccurate.
	2	Uses a problem-solving strategy, but the focus of the problem is incorrect.
	1	Incorrect answer, illogical explanation, or without basis.
	0	Does not provide an answer.
Control of Variable	4	Independent and control variables are correctly identified and form the main focus of the solution.
	3	Variables are correctly identified, but are not made the main focus of the solution.
	2	Listed the variables, but failed to distinguish between independent and control variables.
	1	Did not list any relevant variables at all.
	0	Did not provide an answer.
Probability Reasoning	3	Correct answer with quantitative reasoning (based on numbers/data).
	2	Correct answer with qualitative reasoning (based on verbal descriptions).
	1	The answer is illogical or demonstrates a misunderstanding.
	0	Did not provide an answer.
Hypothetical Deductive Reasoning	4	Uses comparisons and determines the final result accurately.
	3	Uses comparisons correctly, but the final result is inaccurate.
	2	Uses a problem-solving strategy, but the focus of the problem is incorrect.
	1	Guesses the answer at random with illogical reasoning.
	0	Does not provide an answer.

To determine the level of cognitive development, the raw test scores are converted to a scale of 100 using the following formula:

$$x = \frac{Total\ Score}{Maximum\ Score} \times 100$$

Meanwhile, the score for each reasoning indicator is calculated using the formula:

$$y = \frac{Average\ Indicator\ Score}{Maximum\ Indicator\ Score} \times 100$$

The values of pure students were converted to a 100-point scale and grouped into four categories: Operational Concrete, Early Transition, Late Transition, and Formal (Fernando et al., 2024). In addition, it analyzes error patterns, identifies trend answers, and identifies difficulties for dominant students at each question level.

Table 2. Level of scientific reasoning

Dimention	Scale
Operational Concrete	$0 \leq x < 25$
Early Transition	$25 \leq x < 50$
Late Transition	$50 \leq x < 75$
Operational Formal	$75 \leq x < 100$

RESULT AND DISCUSSION

The study aims to describe the reasoning ability of scientific students regarding the material on static fluids, divided into three subtopics: pressure hydrostatics, Pascal's law, and Archimedes' principle. The data analysis provides an overview of the students' scores, showing that the 84 students in the sample had an average scientific reasoning score of 49.42. The lowest score recorded was 8, whilst the highest was 92, with a standard deviation of 21.22. This indicates considerable variation in scientific reasoning ability among the students.

Table 3. Scientific reasoning scores in each indicator

Scientific Reasoning Indicators	Mean	Std. Deviation	Score 0 (%)	Score 1 (%)	Score 2 (%)	Score 3 (%)	Score 4 (%)
Correlational Reasoning	47.32	1.00	6.0	23.8	33.3	32.1	4.8
Proportional Reasoning	64.29	1.28	4.8	15.5	16.7	19.0	44.0
Control of Variable	49.26	1.41	16.7	14.3	23.8	20.2	25.0
Probability Reasoning	52.38	0.82	6.0	31.0	45.2	17.9	-
Hypothetical Deductive Reasoning	34.38	1.24	27.40	22.6	23.8	21.4	4.8

Based on the analysis of each indicator in Table 5, the students' scientific reasoning profiles show varied results. This analysis indicates that, for the proportional reasoning indicator, almost half of the students achieved the highest score, score 4, representing 44%. This indicates that the majority of students were able to identify relationships between variables and analyze data quantitatively; that is, they possessed a good mathematical ability to relate ratios and proportions. Conversely, for the hypothetical-deductive reasoning indicator, only 4.8% of students scored 4, whilst the largest percentage was 27.40% at score 0. This suggests that many students are still unable to evaluate hypotheses in the given questions and design experimental set-ups to test the problems presented. Meanwhile, for the probability reasoning indicator, most students were at an intermediate level, with 45.2% scoring 2. Students' abilities in the correlational reasoning and control of variables indicators were at a fairly consistent intermediate level.

Subsequently, students' cognitive development levels were categorized according to Piaget's theory, as measured by five indicators of scientific reasoning: correlational reasoning, proportional reasoning, control of variables, probability reasoning, and hypothetical-deductive reasoning. The distribution of students' cognitive levels is presented in Figure 1.

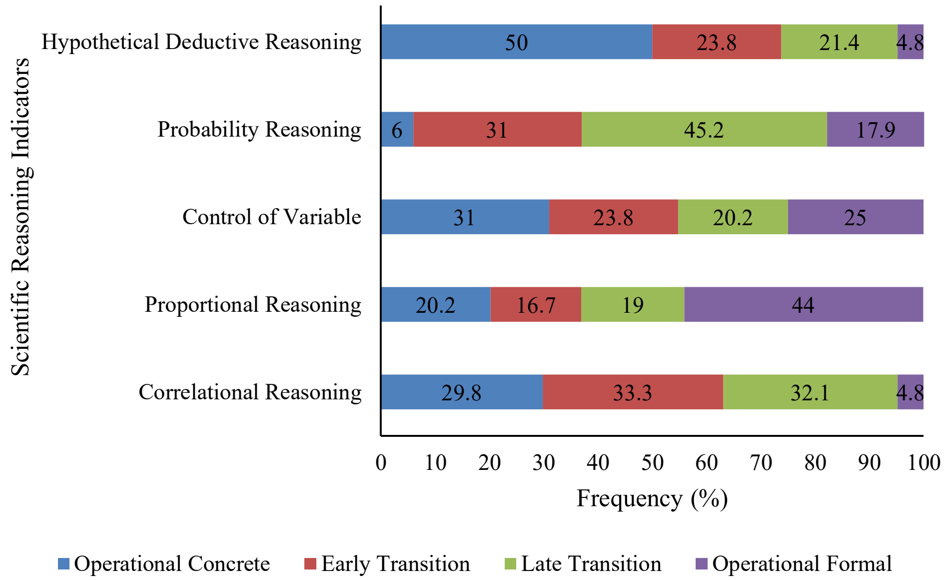

Figure 1. Scientific reasoning levels in every indicator

Figure 1 shows that the distribution of students' reasoning levels across each indicator varies. For the proportional reasoning indicator, 44% of students have reached the formal operational level, the highest percentage among the indicators. Meanwhile, for the hypothetical-deductive reasoning indicator, 50% of students are still at the concrete operational level, and only 4.8% have reached the formal operational level. The probability reasoning indicator also showed low results, with the majority of students at the late transitional level at 45.2%. For the correlational reasoning indicator, the largest proportions of students were in the late transitional stage (33.3%) and the early transitional stage (32.1%). In contrast, for the control-of-variables indicator, the distribution of students was fairly even across the concrete operational, transitional, and formal operational stages.

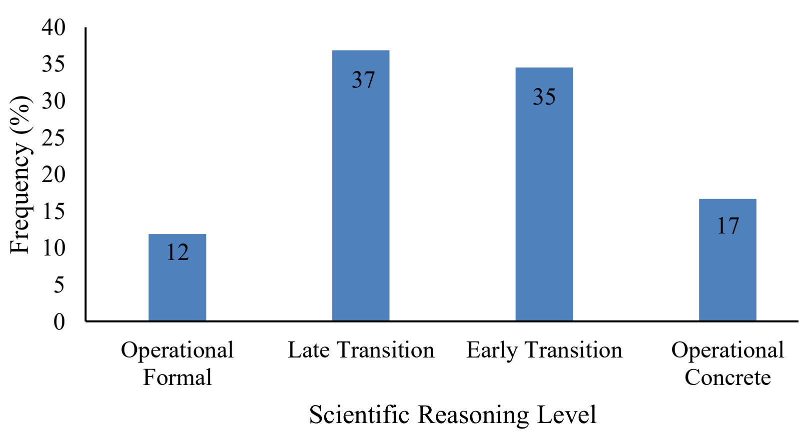

Figure 2. Student scientific reasoning levels

As shown in Figure 2, the majority of students are at the Late Transition stage (37%) and the Early Transition stage (35%). Only a small proportion of students (12%) have reached the Formal Operational stage, whilst 17% are still at the Concrete Operational stage.

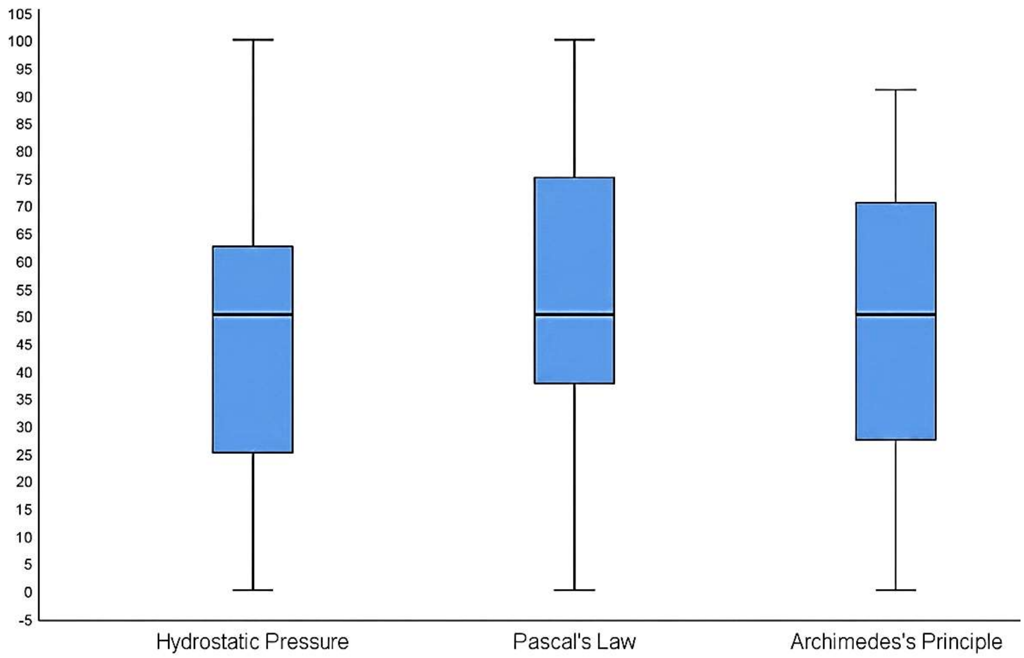

Figure 3. Score for scientific reasoning ability in each subtopic of static fluids

Based on Figure 3, the median score for students across the three subtopics of static fluids, namely, hydrostatic pressure, Pascal's Law and Archimedes' Principle, was the same, at 50. Although the medians were identical, the distribution of students' scores across the subtopics showed quite striking differences. In the hydrostatic pressure subtopic, the distribution of students' scores was the lowest of the three. This is evident from the very low lower quartile, around 25, accompanied by a fairly wide interquartile range. Meanwhile, the subtopic on Archimedes' Principle occupies the middle position, with a lower quartile of around 25–30 and an upper quartile reaching 70. Conversely, the subtopic on Pascal's Law exhibits the best score distribution, characterized by the highest upper quartile, around 75, as well as a narrower range of scores compared to the other two subtopics.

Table 4. Classification of dominant error types

No	Subtopic	Scientific Reasoning	Observed Student Answer	Inferred Error Category
1	Pressure Hydrostatic	Correlational Reasoning	"Hydrostatic pressure is directly proportional to depth, so the deeper the depth, the higher the pressure."	Students tended to score 3, indicating they understood the relationship between depth and pressure but overlooked the effect of fluid density.
2		Correlational Reasoning	"The hydrostatic pressure in container D will be the highest or greater than that in the other three containers."	The majority of answers scored 1. Students were able to identify the object with the highest pressure, but failed to provide a supporting logical explanation.

3	Pascal's Law	Proportional Reasoning	"F2 = 25,000 N"	Many students scored 3. Students could apply the formula, but were unable to demonstrate the mathematical conversion process from cross-sectional area to radius.
4		Control of Variable	Most students did not provide an answer.	Most students scored 0, indicating they were unable to identify the independent and control variables for investigating the effect of cross-sectional area on force.
5	Archimedes' Principle	Probability Reasoning	"The cube will sink because its density is greater than that of the fluid."	The majority of students scored 2. Students were limited to qualitative explanations and failed to integrate quantitative data into probability calculations.
6		Proportional Reasoning	"$V_{tercelup\ X} = \frac{1}{2} V_{total}$ The volume of the block that is submerged is 0.5 or 50% of the total volume."	Students' answers predominantly scored 4, meaning they were highly proficient at determining the percentage of an object's volume submerged through accurate calculations and conversions.
7		Hypothetical Deductive Reasoning	"Wood has a lower density than water, so it floats even though it is large. Whereas marbles (glass/iron) have a density greater than water, so they sink even though they are small."	Students' answers mostly scored 1. This indicates that students passively understood the theory of density but failed to design an experiment and conduct systematic verification.
8		Control of Variable	"Systems A and B were chosen because the difference in floating and sinking behaviour is caused solely by the difference in the objects' densities, not by the type of liquid."	Students tend to score 3. They understand the variables conceptually but fail to articulate the experimental design formally.
9		Probability Reasoning	"Objects B and C are certain to float because the densities of B and C are smaller than that of A."	Most students score 2. They have understood the relationship between density, but fail to convert logical certainty into numerical probability values (100%).
10		Hypothetical Deductive Reasoning	Some students did not provide an answer.	Most students scored 0. Students failed to predict and formulate hypotheses about an object's state based on the given premises.

Overall, students have demonstrated an understanding of the basic concepts in the static fluids module, but have encountered significant difficulties in procedural and quantitative reasoning. In the sub-topics of Hydrostatics and Archimedes' Principle, students tend to provide conceptually accurate qualitative explanations, but often overlook other supporting variables and fail to translate theory into accurate numerical probability representations. The most critical difficulties were found in the 'Hypothetical-Deductive' and 'Control of Variables' indicators, namely that students were stuck in a passive mastery of theory but were unable to formulate hypotheses, determine control variables, or design systematic experimental procedures to validate their scientific ideas. On the other hand, although proportional reasoning showed better results in volume calculations based on Archimedes' principle, students were still often confused when required to outline the steps for deriving the formula independently; consequently, the final results were frequently inaccurate because students were not yet accustomed to using scientific logic as a basis for predicting the behavior of objects in specific situations.

Based on the analysis conducted, students' overall scientific reasoning skills are at a moderate level. This is consistent with research conducted by Anjiana et al. (2026), Dinata et al. (2025), and Khoirina et al. (2018), which indicates that the scientific reasoning skills of upper secondary school students are generally at a moderate to low level. The results of this study also reveal that the majority of students are still at the transitional stage, with 35% in the early transitional stage and 37% in the late transitional stage. This is consistent with research by Moore & Rubbo (2012), Rosdiana et al. (2019), and Valanides (1998), which found that, on average, students' scientific reasoning abilities remain at the concrete operational to transitional levels.

Based on the research conducted, students tend to struggle with correlational reasoning, probability, variable control, and hypothetico-deductive reasoning. Students find it most difficult to solve problems related to these four types of reasoning because they struggle to establish cause-and-effect relationships (Isnawati et al., 2024); they are stronger at concrete reasoning than abstract reasoning (Anjiana et al., 2026), and teaching methods often involve students merely memorizing rather than understanding concepts (Utami et al., 2020). Interestingly, although students are reasonably capable in proportional reasoning, their probability skills remain low. This occurs because students struggle to transfer their understanding of proportional reasoning to the more abstract context of probability (Begolli et al., 2021). In fact, sound proportional reasoning requires spatial ability, not merely the memorization of formulas. This spatial ability is an even stronger predictor of scientific reasoning than procedural mathematical achievement (Luo et al., 2025; Möhring et al., 2016, 2018). This is clearly evident from the students' answers, many of which remain trapped in qualitative explanations, as shown in Figure 4. These answers indicate that students tend to merely mention general relationships between variables without being able to explain the quantitative relationships or the proportional representations underpinning Archimedes' principle. Furthermore, students remain weak in controlling variables and in hypothetical-deductive reasoning. These findings align with research by Ari et al. (2024), Khoirina et al. (2018), and Zhou et al. (2016), which states that students still struggle to design experiments, identify relevant variables, formulate hypotheses, and determine the factors influencing a phenomenon.

Three objects, A, B and C, with different densities satisfy the condition that $\rho_A > \rho_B > \rho_C$. If object A floats in water, what is the probability that object B or C will float when placed in the same water?

benda B dan C akan terapung jika benda A yang memiliki masa jenis lebih Berat dari B dan C mengapung

Objects B and C will float if object A, which has a higher density than B and C, also floats

Figure 4. Example answer: students on the archimedes subtopic

Regarding static fluids, most students have not yet reached the formal operational stage of thinking. Among the three subtopics, the highest average level of student understanding was found in Pascal's Law, followed by Archimedes' Principle, whilst hydrostatic pressure received the lowest average score. Regarding Pascal's Law, students are reasonably capable of performing procedural calculations but still struggle to understand relationships among quantities, such as how cross-sectional area affects the resulting force. This is consistent with research by Irma et al. (2022), which found that students can perform procedural calculations involving force but struggle to understand the relationship between force and cross-sectional area. Furthermore, senior secondary school students possess adequate procedural skills but are weak in conceptual understanding and reasoning regarding Pascal's Law (Rachmawati et al., 2024; Saputro et al., 2025).

In contrast to Archimedes' principle, students still struggle to identify an object's state and to compare its density with that of a fluid. This is consistent with research (Mansyur et al., 2022; Sukariasih, 2026) indicating that students face significant difficulties in distinguishing between the states of floating, suspended, and sinking objects, as they tend to rely on the object's mass rather than the comparison of the object's density with that of the fluid. Furthermore, many students hold strong misconceptions and exhibit weak reasoning regarding buoyant force and the volume of fluid displaced, making it difficult for them to connect Archimedes' principle with everyday phenomena (Kusairi et al., 2020; Putranta & Afifah, 2025; Rosyidah et al., 2020). Overall, students' understanding is lowest in the sub-topic of hydrostatic pressure because they struggle to connect the various factors affecting it and are weak in the qualitative application of concepts (Amiruddin et al., 2026; Bessas et al., 2024; Yusro et al., 2023).

This situation is influenced by an education system that, to this day, remains overly focused on rote learning and places insufficient emphasis on inquiry-based and problem-solving approaches (Hasruddin & Aulia, 2023). Students' scientific reasoning skills remain low because most students are still weak in qualitative and multivariable reasoning and rarely receive instruction that deliberately trains the scientific thinking process (Luo et al., 2025; Valanides, 1998). This inability to reach the stage of formal reasoning directly contributes to students' low achievement across various scientific disciplines (Lawson, 1985).

Therefore, a more appropriate learning approach is required to help students move from concrete thinking towards more abstract and logical reasoning. Improvement efforts can be made by integrating procedural and conceptual e-scaffolding in Modeling Instruction, as well as cognitive science-based strategies (Yana et al., 2025). Furthermore, learning models such as experiential learning, which utilizes students' real-world experiences (Kolb & Kolb, 2009), and design thinking, which trains students in creative and iterative problem-solving (Razzouk & Shute, 2012), are also increasingly relevant for strengthening students' scientific reasoning.

Furthermore, students' scientific reasoning skills can be effectively enhanced by applying a guided inquiry model supported by visual aids, such as multidimensional thinking diagrams (Anjani, 2020), and by formative assessments that provide continuous feedback (Saiya et al., 2023). This approach helps students integrate hypotheses, empirical data, and concepts in a structured manner, whilst practicing various patterns of scientific reasoning, such as controlling variables, proportional reasoning, and conservation, so that students do not merely memorize but are able to think scientifically like scientists.

LIMITATION OF THE STUDY

This study involved respondents from just one state senior secondary school in Malang. Consequently, the researchers were unable to compare students' scientific reasoning abilities across different schools. Nor could this study provide a cross-sectional overview of school levels, for example, between lower secondary and senior secondary schools, or across regions, as part of a broader study. The researchers present data only on scientific reasoning skills and error patterns among senior secondary school students within a single school context. Therefore, the results of this study cannot be generalized to the entire population of senior secondary school students in Indonesia and merely reflect conditions within the specific school context under investigation.

CONCLUSION

High school students' scientific reasoning skills in static fluids were, on the whole, in the moderate range, with an average score of 49.42. The majority of students were still in the transitional stages of cognitive development, namely Late Transition (37%) and Early Transition (35%), and only 12% had reached the formal operational stage. Based on scientific reasoning indicators, students achieved the highest scores in proportional reasoning, but were weak in hypothetical-deductive reasoning and variable control. The patterns of errors that emerged indicate that students are stronger at understanding concepts qualitatively and passively, but have difficulty formulating hypotheses, determining control variables, and systematically designing experimental procedures.

Furthermore, students' highest level of understanding was found in Pascal's Law, followed by Archimedes' Principle, whilst hydrostatic pressure achieved the lowest average score. This occurred because students tended to perform procedural calculations well but remained weak in conceptual understanding and reasoning about static fluid. This situation is influenced by an education system that remains focused on rote learning and places insufficient emphasis on inquiry-based approaches and problem-solving. Therefore, a transformation in learning is required through approaches such as modeling instruction and experiential learning to more sustainably enhance students' scientific reasoning skills.

DECLARATION OF GENERATIVE AI USAGE IN THE WRITING PROCESS

During the writing of this manuscript, the authors employed Grok and Gemini AI to assist with language refinement, paraphrasing several sections to improve clarity and readability, and enhancing the overall quality of the academic writing. The authors have reviewed and edited the content generated by this tool and assume full responsibility for the content of the published article.

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