

ANALYSIS THE QUALITY OF HIGH SCHOOL STUDENTS' ANSWERS USING SOLO TAXONOMY BASED INSTRUMENTS

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ABSTRAK

Pemahaman konsep fluida pada siswa sekolah menengah atas masih tergolong rendah karena banyak siswa mampu menggunakan rumus, tetapi mengalami kesulitan dalam menghubungkan konsep secara menyeluruh. Penelitian ini bertujuan untuk menganalisis kualitas jawaban siswa pada materi fluida berdasarkan Taksonomi SOLO. Penelitian menggunakan metode deskriptif kuantitatif dengan melibatkan 80 siswa kelas XI SMA Negeri 1 Medan yang dipilih melalui teknik cluster sampling. Instrumen penelitian berupa tes diagnostik berbasis Taksonomi SOLO yang terdiri atas 12 butir soal valid. Data dianalisis dengan mengelompokkan jawaban siswa ke dalam level SOLO dan menghitung distribusi tingkat pemahaman yang dicapai. Hasil penelitian menunjukkan bahwa instrumen memiliki reliabilitas yang baik dengan koefisien sebesar 0,887, daya pembeda yang didominasi kategori sangat baik, serta tingkat kesukaran yang bervariasi. Analisis jawaban siswa menunjukkan bahwa level multistruktural merupakan tingkat pemahaman yang paling dominan. Temuan ini menunjukkan bahwa sebagian besar siswa telah mampu memahami beberapa konsep yang relevan, tetapi belum mampu mengintegrasikannya secara utuh sehingga pemahaman yang dimiliki masih cenderung berada pada tahap surface learning dibandingkan deep learning. Oleh karena itu, diperlukan strategi pembelajaran yang dapat mendorong siswa mencapai tingkat pemahaman yang lebih tinggi.

Kata Kunci: *Analisis, Kualitas Hasil Jawaban, Taksonomi SOLO*

ABSTRACT

Students' understanding of fluid concepts at the senior high school level remains relatively low, as many students are able to apply formulas but still experience difficulties in connecting concepts comprehensively. This study aimed to analyze the quality of students' responses on fluid topics based on the SOLO Taxonomy. A quantitative descriptive method was employed involving 80 eleventh-grade students of SMA Negeri 1 Medan selected through cluster sampling. The research instrument was a SOLO Taxonomy-based diagnostic test consisting of 12 valid items. Data were analyzed by classifying students' responses into SOLO levels and determining the distribution of understanding levels achieved. The results showed that the instrument had good reliability with a coefficient of 0.887, discrimination indices predominantly in the very good category, and varied levels of difficulty. The analysis revealed that the multistructural level was the most dominant level of understanding achieved by students. This finding indicates that most students were able to understand several relevant concepts but had not yet integrated them into a coherent conceptual framework. Consequently, students' understanding tended to reflect surface learning rather than deep learning. Therefore, instructional strategies that promote higher levels of conceptual understanding are needed.

Keywords: *Analysis, Quality of Answer Results, SOLO Taxonomy*

INTRODUCTION

Physics learning at the senior high school (SHS) level is intended to help students develop an understanding of scientific concepts and phenomena that occur in everyday life. One of the fundamental topics in physics is fluids, which encompass static and dynamic fluids and are closely related to various real-world applications, such as hydraulic systems, buoyancy, blood circulation, and water flow. Therefore, learning activities should not merely emphasize the memorization of formulas and procedural problem-solving but should also foster students' scientific reasoning and conceptual understanding. Nevertheless, numerous studies have indicated that students' scientific literacy and conceptual understanding in physics remain unsatisfactory, particularly in fluid topics. According to the Programme for International Student Assessment (PISA) (OECD, 2023), only around 34% of Indonesian students achieved Level 2 or above in scientific literacy, considerably lower than the OECD average of 76%. This finding suggests that many students still experience difficulties in interpreting information, explaining scientific phenomena, and applying evidence-based reasoning to solve problems.

The challenges faced by students are also reflected in their understanding of static fluid concepts, including hydrostatic pressure, Pascal's law, and Archimedes' principle. Although many students are capable of recalling definitions and applying formulas, they often struggle to connect related concepts into a coherent conceptual framework. As a result, their understanding tends to remain fragmented and superficial. From the perspective of the SOLO Taxonomy (Structure of the Observed Learning Outcomes), students' responses frequently indicate understanding at the unistructural and multistructural levels, where concepts are treated independently rather than integrated meaningfully. Previous studies have reported substantial misconceptions in fluid topics, including hydrostatic pressure (16.19%), Pascal's law (39.04%), and Archimedes' principle (45.71%) (Ahmadi et al., 2024). Other studies have similarly revealed that misconceptions in static fluid concepts can reach as high as 88.5% among students (Atmaja & Samsudin, 2024; Hutasoit et al., 2025; Muki et al., 2025; Putri et al., 2023; Kurniawan, 2023). These findings indicate that conventional assessments, which generally emphasize factual recall and procedural competence, are often unable to capture the depth and quality of students' conceptual understanding.

Preliminary observations conducted through student surveys revealed that most learners tend to prefer conceptual and analytical approaches to learning physics. Approximately 76.7% of students reported that they understand physics concepts more effectively when relationships among concepts are emphasized rather than memorized, while 80% expressed interest in solving multi-step and challenging problems. In addition, 76.6% stated that learning activities involving higher-order thinking contribute positively to their understanding of physics concepts (Fatmawati et al., 2025; Koto & Ilhami, 2023). Despite these preferences, nearly half of the students perceived that classroom assessments still focus primarily on memorization and routine procedures. This situation suggests a discrepancy between students' cognitive characteristics and the assessment practices commonly implemented in schools.

One approach that can be used to examine students' conceptual understanding more comprehensively is the SOLO Taxonomy. Developed by Biggs and Collis, the SOLO Taxonomy classifies learning outcomes according to the structural complexity of students' responses, ranging from prestructural, unistructural, and multistructural to relational and extended abstract levels (Biggs & Collis, 1982). Unlike Bloom's Taxonomy, which emphasizes cognitive processes, the SOLO Taxonomy focuses on the quality, organization, and integration of knowledge demonstrated in students' responses (Fernandez & Guzon, 2025). Consequently,

it provides a useful framework for analyzing the depth of students' understanding and identifying how concepts are connected within their cognitive structures.

Several previous studies have demonstrated that SOLO-based assessments can effectively reveal students' levels of understanding and misconceptions in physics learning. Research on fluid concepts has shown that SOLO-based analyses are capable of identifying misconceptions related to hydrostatic pressure, buoyancy, and Bernoulli's principle (Hartanti et al., 2021). However, most existing studies have focused primarily on the identification of misconceptions, while limited attention has been given to examining the overall quality of students' responses and describing their conceptual understanding based on the hierarchy of SOLO levels. As a result, further research is needed to provide a more detailed picture of students' cognitive structures and the extent to which they are able to integrate and apply fluid concepts meaningfully.

Based on these considerations, this study aims to analyze the quality of senior high school students' responses on fluid topics using a diagnostic test based on the SOLO Taxonomy. The analysis is intended to describe students' levels of conceptual understanding, identify patterns of misconceptions, and reveal the characteristics of students' cognitive structures as reflected in their responses. Through this approach, the study is expected to provide a more comprehensive understanding of students' learning outcomes beyond mere correctness of answers.

The findings of this study are expected to offer valuable contributions to several stakeholders. For students, the results may help identify their current level of conceptual understanding and encourage the development of more integrated and higher-order thinking skills. For teachers, the findings can provide diagnostic information regarding students' learning difficulties, misconceptions, and patterns of understanding, which may support the design of more effective instructional strategies. For schools, the study can contribute to improving the quality of physics learning and assessment practices. Furthermore, the results may serve as a useful reference for future researchers interested in investigating students' conceptual understanding and cognitive development using the SOLO Taxonomy in various educational contexts.

METHOD

This study employed a quantitative descriptive research design aimed at analyzing the quality of students' responses on fluid concepts based on the SOLO Taxonomy framework. The study focused on describing students' levels of conceptual understanding through the analysis of their responses to diagnostic test items. The SOLO Taxonomy was used as an analytical framework to classify students' understanding into five hierarchical levels: prestructural, unistructural, multistructural, relational, and extended abstract.

The research was conducted at SMA Negeri 1 Medan, North Sumatra, in January 2026. The school was selected because it had not previously implemented SOLO Taxonomy-based assessments in physics learning, providing an opportunity to obtain a comprehensive picture of students' conceptual understanding of fluid topics. The population of this study consisted of 432 Grade XI students enrolled at SMA Negeri 1 Medan. A subject of 80 students was selected using a cluster sampling technique and was distributed across three classes, with 20 students in one class, and 60 students in two class. The participants completed learning activities related to fluid concepts, including hydrostatic pressure, Pascal's law, Archimedes' principle, and fluid dynamics.

Data was collected through a diagnostic test based on the SOLO Taxonomy. The instrument consisted of 17 multiple-choice items designed to assess students' conceptual understanding at different SOLO levels. The test items incorporated various forms of representation, including verbal statements, numerical information, graphical representations, and visual illustrations, to provide a more comprehensive evaluation of students' understanding. Prior to implementation, the instrument was reviewed by experts in physics education and educational assessment to ensure the appropriateness of the content, construction, and language. After the validation process, the diagnostic test was administered to the selected students. Students' responses were then collected and categorized according to the SOLO Taxonomy criteria.

The data were analyzed using descriptive quantitative techniques. Students' responses were classified into SOLO levels, namely prestructural, unistructural, multistructural, relational, and extended abstract. The analysis focused on determining the distribution of students across these levels and describing the quality of their conceptual understanding of fluid concepts. Frequencies and percentages were calculated to identify the proportion of students at each SOLO level. Furthermore, students' response patterns were examined to reveal the characteristics of their understanding and to identify areas where conceptual difficulties were most prominent. The results of the analysis were then interpreted to provide a comprehensive profile of students' cognitive structures and conceptual understanding of fluid topics.

HASIL DAN PEMBAHASAN

Result

The development of the SOLO Taxonomy-based assessment instrument was carried out following the Borg and Gall procedure, beginning with the identification of potential and problems and ending with the production of a feasible final product. At the initial stage, it was found that the school already had assessment instruments to measure students' cognitive achievement; however, these instruments had not specifically classified students' understanding based on SOLO Taxonomy levels. Therefore, an additional instrument was required to provide a more structured description of students' conceptual understanding. Literature reviews and needs analyses were then conducted to formulate indicators and develop the test blueprint. Based on these results, an initial instrument consisting of 17 essay items representing SOLO levels was constructed and subsequently validated by two experts. Following the validation process, revisions were made and the number of items was reduced to 14 items that were considered suitable for field testing.

The first preliminary field test involved 10 students. The analysis showed that 8 items, namely items 1, 2, 3, 5, 8, 9, 10, and 13, did not meet the validity criteria. Nevertheless, these items were not immediately discarded because they were still aligned with the intended indicators and SOLO levels. Instead, revisions were made regarding the clarity of wording, contextual relevance, and conceptual accuracy. After revision, a second preliminary field test indicated that all items met the required validity criteria. Qualitative item analysis revealed that 6 items (items 1, 12, 14, 15, 16, and 17) were accepted, 8 items (items 2, 3, 4, 5, 7, 8, 9, and 10) required revision, and 3 items (items 6, 11, and 13) were rejected.

The main field test was subsequently conducted with 60 students. The results indicated that 2 items failed to satisfy the validity requirements and were therefore removed from the instrument. After the second revision stage, the final instrument consisted of 12 valid items

distributed across SOLO levels S2, S3, S4, and S5. The reliability coefficient of the instrument was 0.887, indicating high reliability. The validity coefficients of the final items ranged from 0.480 to 0.815. Most items demonstrated very good discrimination power, with values ranging from 0.6875 to 0.875, although one item showed a lower discrimination index of 0.1875. The difficulty indices ranged from 0.3500 to 0.9500, indicating that the instrument contained items with varying levels of difficulty and could assess students across different ability levels. Based on these findings, the instrument was considered valid, reliable, and feasible for use as an assessment tool in physics learning.

Based on the data analysis after the item deleted, it was concluded that the presentation of students who can answer the questions correctly for each level can be seen through Table 1 below.

Table 1. Presentation for Each Level

Level SOLO	Percentage
S2	69%
S3	72%
S4	61%
S5	59%

After being percentaged for each level, the data analysis figures are then percentaged as a whole to clearly see which level students are most capable and at which level students are less capable, as well as the data in Figure 1.

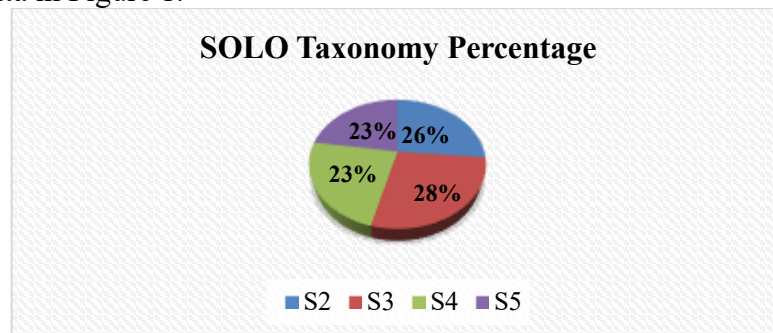


Figure 1. Taxonommy Percentage

Based on the results of the percentage of the SOLO Taxonomy level in students at SMA Negeri 1 Medan in Picture 1, it can be concluded that students' cognitive abilities tend to be at the intermediate level with a dominance at the multistructural level (S3) of 28%, which shows that most students have been able to understand several concepts separately but have not been able to integrate them thoroughly. In addition, there are 26% of students at the unistructural level (S2) which indicates that there are still quite a lot of students who only understand one aspect of the concept in a limited way. Meanwhile, 23% of students have reached relational (S4) and extended abstract (S5) levels, each of which shows that some students already have high-level thinking skills, such as connecting various concepts in an integrated manner and generalizing and applying them to new situations.

The relatively high percentage at the unistructural level (69%) indicates that most students were able to identify and understand at least one relevant aspect of a problem. Students at this level could recognize basic concepts and retrieve essential information required to answer the questions correctly. This result suggests that the majority of students have acquired fundamental conceptual knowledge related to fluid mechanics. Nevertheless, achievement at

the unistructural level alone does not necessarily indicate deep understanding because students are still focusing on isolated aspects of the concept without considering broader relationships.

The highest percentage was observed at the multistructural level (72%), indicating that students were generally capable of identifying several relevant concepts within a problem. At this level, students could recall and use multiple pieces of information simultaneously. This finding reflects that students possess a relatively strong conceptual foundation and can recognize various principles related to fluid phenomena. However, students at the multistructural level tend to process concepts separately rather than integrating them into a coherent conceptual framework. Consequently, although students can identify several relevant variables, formulas, or principles, they may still struggle to explain how these elements interact within a complex problem-solving situation.

The dominance of the multistructural level is particularly significant because it suggests that students' learning outcomes are concentrated in the transition between basic understanding and higher-order thinking. In other words, students have progressed beyond simple recognition of concepts but have not yet fully developed the ability to establish meaningful relationships among those concepts. This pattern is commonly observed in science learning, where students often master individual concepts but encounter difficulties when required to connect multiple concepts simultaneously.

A notable decline can be observed between the multistructural level (72%) and the relational level (61%), representing a decrease of approximately 11 percentage points. This decrease indicates that many students experienced difficulties when required to integrate several concepts into a unified understanding. At the relational level, students are expected to recognize the relationships among concepts and apply them in a coordinated manner to solve problems. The lower achievement at this level suggests that although students understand individual concepts, many have not yet developed the ability to synthesize information effectively. This finding may indicate that classroom learning activities have been successful in promoting conceptual acquisition but may provide fewer opportunities for students to engage in tasks requiring conceptual integration and analytical reasoning.

The percentage at the extended abstract level (59%) provides further evidence of the challenges students face in higher-order thinking processes. The extended abstract level represents the highest stage of SOLO Taxonomy and requires students to generalize principles, formulate hypotheses, transfer knowledge to unfamiliar contexts, and construct abstract reasoning beyond the information explicitly provided. Although the percentage remains relatively high compared to findings reported in many previous studies, it is still the lowest among all SOLO levels. This result suggests that students encounter increasing difficulty as cognitive demands become more complex and abstract.

The relatively small difference between the relational level (61%) and the extended abstract level (59%) is also noteworthy. The difference of only two percentage points indicates that students who successfully reach the relational level tend to possess the potential to perform at the extended abstract level as well. This finding suggests that once students are able to integrate concepts effectively, the transition toward higher-order abstraction becomes more achievable. Therefore, strengthening students' relational thinking may serve as a key strategy for promoting advanced cognitive development.

Overall, the pattern of results demonstrates a gradual decline in achievement as the SOLO Taxonomy level increases. Such a pattern is theoretically expected because each higher level requires more sophisticated cognitive processes than the previous level. Students

generally performed well when tasks involved identifying concepts and understanding multiple pieces of information. However, their performance decreased when they were required to establish relationships among concepts, construct integrated explanations, and apply knowledge to novel situations. These findings indicate that the primary challenge faced by students is not conceptual recognition but rather conceptual integration and abstraction.

The quantitative findings are supported by the interview conducted with the physics teacher, who stated that students at SMA Negeri 1 Medan generally possess high academic ability and strong critical-thinking skills. The relatively high percentages obtained at all SOLO levels support this perception, demonstrating that students have achieved a satisfactory level of conceptual understanding. Furthermore, the teacher emphasized that physics instruction at the school focuses on conceptual understanding rather than memorization of formulas. This statement is reflected in the students' performance at the multistructural, relational, and extended abstract levels, where successful responses require conceptual reasoning rather than simple recall.

However, the SOLO Taxonomy analysis provides a more nuanced understanding than the teacher's general observations. Although students are perceived as highly capable, the dominance of the multistructural level indicates that many students still operate at a stage where concepts are understood separately rather than as interconnected systems of knowledge. Therefore, the findings suggest that future instructional practices should emphasize inquiry-based learning, problem-solving activities, and tasks that encourage students to integrate concepts and apply them in unfamiliar contexts. Such approaches may facilitate students' progression from multistructural understanding toward relational and extended abstract thinking.

Analysis of Item Discrimination Index and Student Ability Profiles

Item discrimination analysis was conducted to determine the extent to which each test item could distinguish between students with high levels of achievement and those with low levels of achievement. In Classical Test Theory (CTT), the discrimination index reflects the effectiveness of an item in differentiating students based on their mastery of the measured concepts. A high discrimination index indicates that students with higher ability are more likely to answer the item correctly, whereas students with lower ability tend to answer incorrectly.

In this study, students were categorized into three groups based on their total test scores: the upper group, the middle group, and the lower group. The upper and lower groups were used to calculate the discrimination index because these groups represent the highest and lowest levels of achievement, thereby providing a clearer measure of item discrimination. Table 2 presents the percentage of correct responses for the upper and lower groups, along with the discrimination index for each item.

Table 2. Percentage of Correct Responses and Discrimination Index

Item	Upper Group	Lower Group	Difference	Discrimination Index
Q1	87.5%	12.5%	75%	0.75
Q2	81.25%	6.25%	75%	0.75
Q3	93.75%	6.25%	87.5%	0.875
Q4	100%	12.5%	87.5%	0.875
Q5	100%	25%	75%	0.75

Q6	100%	25%	75%	0.75
Q7	100%	25%	75%	0.75
Q8	100%	12.5%	87.5%	0.875
Q9	87.5%	0%	87.5%	0.875
Q10	100%	81.25%	18.75%	0.188
Q11	100%	31.25%	68.75%	0.688
Q12	100%	31.25%	68.75%	0.688

The average percentage of correct responses in the upper group was 95.83%, whereas the lower group achieved only 22.40%. The difference between these groups reached 73.43 percentage points, indicating a substantial gap in conceptual understanding and overall achievement.

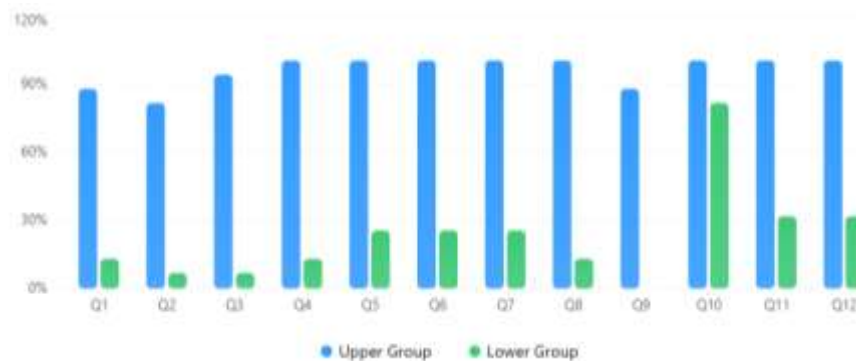


Figure 2. Comparison of Correct Response Rates

Figure 2 clearly demonstrates the substantial differences between the upper and lower groups across most test items. Such a pattern is characteristic of a high-quality instrument with strong discriminatory power. The large gap in performance indicates that the majority of the items successfully differentiate students according to their level of conceptual understanding.

Profile of the Upper Group

Students in the upper group demonstrated exceptionally high performance, with an average correct response rate of 95.83%. This finding indicates that these students had mastered nearly all learning indicators assessed by the instrument. Notably, all students in the upper group answered Items Q4, Q5, Q6, Q7, Q8, Q10, Q11, and Q12 correctly. Such consistency suggests that these students possessed a well-developed understanding of the underlying concepts measured by the test. From a cognitive perspective, the upper group appears capable of not only recalling information but also applying, analyzing, and integrating conceptual knowledge across different contexts. Their performance reflects a robust conceptual framework that enables them to solve problems effectively and accurately.

Profile of the Middle Group

The middle group occupies the central position within the achievement distribution. Students in this group generally demonstrated a moderate level of conceptual understanding. The performance of the middle group suggests that these students have acquired foundational knowledge of the subject matter but have not yet achieved complete conceptual mastery. They are likely able to answer questions involving basic comprehension and straightforward applications but may encounter difficulties when confronted with tasks requiring higher-order

thinking skills. Educationally, the middle group represents the segment of students with the greatest potential for improvement. Appropriate instructional interventions, such as guided inquiry, problem-based learning, and targeted conceptual reinforcement, may significantly enhance their achievement.

Profile of the Lower Group

The lower group achieved an average correct response rate of only 22.40%, indicating limited mastery of the concepts assessed by the instrument. The low percentage of correct responses suggests that these students experience substantial difficulties in understanding and applying the targeted concepts. Such difficulties may stem from inadequate prior knowledge, misconceptions, ineffective learning strategies, or insufficient conceptual integration. A particularly noteworthy finding is observed in Item Q9, where none of the students in the lower group answered correctly. This result suggests that the concept assessed by Q9 was especially challenging for low-achieving students. Conversely, Item Q10 was answered correctly by 81.25% of the lower group. This unusually high success rate reduced the item's ability to distinguish between high- and low-achieving students, resulting in a relatively low discrimination index.

Item-by-Item Discrimination Analysis

The highest discrimination indices were observed in Items Q3, Q4, Q8, and Q9, each yielding a value of 0.875. These items demonstrated outstanding discriminatory power and were highly effective in differentiating students according to their achievement levels. Items Q1, Q2, Q5, Q6, and Q7 produced discrimination indices of 0.750, which are also considered excellent according to commonly accepted criteria. Similarly, Items Q11 and Q12 yielded discrimination indices of 0.688, indicating strong discriminatory capacity. In contrast, Item Q10 obtained a discrimination index of only 0.188, which falls within the poor category. This low value indicates that both high- and low-achieving students were able to answer the item correctly. Consequently, the item failed to distinguish effectively between different ability levels. Several factors explain the weak discrimination of Item Q10: The item has been too difficult. The distractors has been ineffective. The correct answer has been overly apparent. The cognitive demand for the item has been lower than that of the other items.

The average discrimination index across all items was 0.734 is considered very good, indicating that the instrument possesses strong discriminatory power. Furthermore, 11 out of 12 items (91.67%) achieved discrimination indices greater than 0.40, which is generally regarded as the minimum threshold for high-quality items. Only one item (Q10) fell below this criterion.

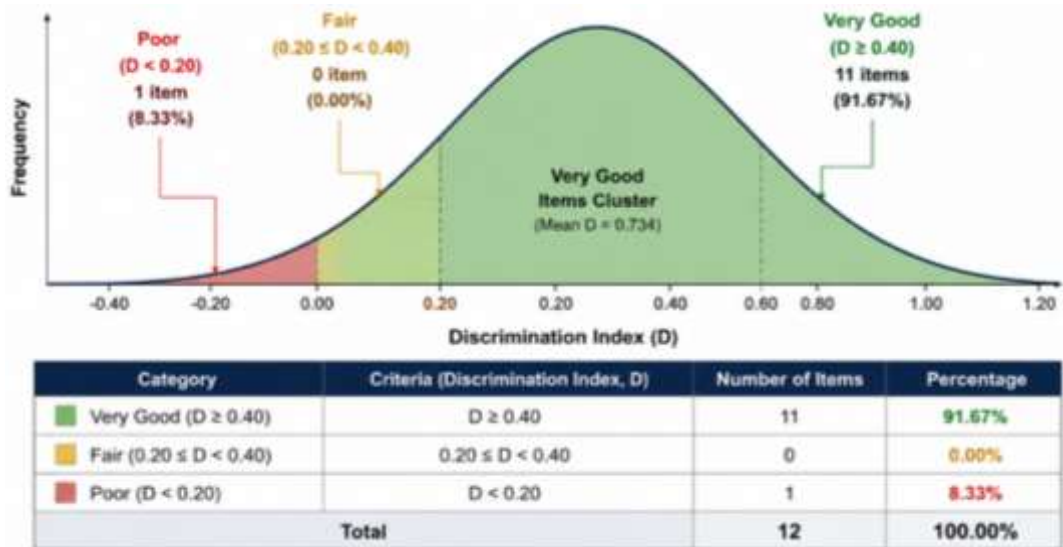


Figure 3. Distribution of Discrimination Index Categories

Figure 3 shows these findings provide strong evidence that the instrument meets one of the fundamental requirements of a high-quality assessment tool, namely the ability to discriminate effectively between students with different levels of achievement.

The results reveal a substantial achievement gap between the upper and lower groups. While the upper group achieved an average success rate of 95.83%, the lower group achieved only 22.40%, resulting in a performance gap of 73.43 percentage points. This considerable difference demonstrates that the instrument successfully captures variations in students' conceptual understanding. The high average discrimination index further confirms that the test is sensitive to differences in student ability and therefore provides meaningful measurement information. From an educational measurement perspective, the findings indicate that the instrument is not only suitable for assessing learning outcomes but also valuable for diagnostic purposes. Specifically, it can be used to identify students who require enrichment activities as well as those who need remedial instruction. Overall, the discrimination analysis demonstrates that the developed instrument possesses strong psychometric quality. The majority of items effectively distinguish between high- and low-achieving students, supporting the validity of the instrument as a measure of students' conceptual understanding within the investigated domain.

Discussion

The findings demonstrate that the developed SOLO Taxonomy-based assessment instrument possesses strong psychometric characteristics and is suitable for measuring students' conceptual understanding of fluid mechanics. The final instrument consisted of 12 valid items with validity coefficients ranging from 0.480 to 0.815 and a reliability coefficient of 0.887. Such results indicate that the instrument consistently measures the intended construct and provides dependable information regarding students' levels of understanding. According to Biggs and Collis (1982), assessment instruments based on SOLO Taxonomy are designed not merely to evaluate correct answers but also to reveal the structural complexity of students' thinking. Therefore, the satisfactory validity and reliability values obtained in this study suggest that the instrument successfully captured variations in students' cognitive development across different SOLO levels.

The strong psychometric quality of the instrument is further supported by the discrimination analysis. The average discrimination index of 0.734 indicates that the majority of items effectively differentiated students with high and low levels of conceptual understanding. This finding is consistent with the argument of Mindayani et al. (2019), who emphasized that SOLO-based assessment instruments should be capable of distinguishing different levels of cognitive performance because each SOLO category represents a qualitatively different stage of understanding. The high discrimination indices found in most items indicate that the developed instrument was sensitive to variations in students' conceptual mastery and therefore suitable for diagnostic as well as evaluative purposes.

An important finding emerging from the SOLO analysis is the dominance of the multistructural level (S3), followed by relatively lower achievements at the relational (S4) and extended abstract (S5) levels. This pattern provides valuable insight into the nature of students' understanding of fluid concepts. Students generally demonstrated the ability to identify multiple relevant concepts, formulas, and variables; however, they often treated these concepts independently rather than integrating them into a coherent conceptual structure. According to Biggs and Collis (1982), multistructural thinking is characterized by the accumulation of separate pieces of information without establishing meaningful relationships among them. Consequently, although students may appear knowledgeable about several aspects of a topic, their understanding remains fragmented.

The predominance of multistructural responses suggests that students have acquired substantial factual and procedural knowledge but have not yet fully developed relational reasoning. Similar findings were reported by Kaharuddin and Hajeniati (2020), who found that students frequently perform well at identifying relevant information yet encounter difficulties when required to connect concepts systematically. Likewise, Mulbar et al. (2017) argued that many learners remain at intermediate SOLO levels because they focus primarily on procedural problem-solving rather than conceptual integration. In the present study, students appeared capable of recalling principles related to fluid pressure, buoyancy, and fluid equilibrium, yet many struggled when these concepts needed to be combined to explain complex phenomena.

The relatively high percentages achieved at the relational and extended abstract levels are nevertheless encouraging. The small gap between S4 (61%) and S5 (59%) indicates that students who successfully establish conceptual relationships tend to possess the potential to generalize their knowledge and apply it to unfamiliar situations. This observation supports the view of Fernandez and Guzon (2025), who argued that relational understanding serves as a critical bridge toward advanced abstraction because students who can integrate concepts are more likely to transfer knowledge across contexts. Similarly, Tian et al. (2024) found that progression from relational to extended abstract thinking is strongly associated with students' ability to construct generalized explanations rather than relying solely on memorized procedures.

Although the overall performance was relatively positive, the gradual decline in achievement from lower to higher SOLO levels reveals persistent challenges in higher-order thinking. This trend is theoretically expected because each successive SOLO level requires increasingly sophisticated cognitive processes. Ahmad et al. (2024) noted that movement across SOLO levels reflects a transition from basic recognition of concepts toward integrated and abstract reasoning. The present findings suggest that students experience increasing cognitive difficulty when required to synthesize information, formulate explanations, and transfer knowledge beyond familiar contexts.

The observed pattern may also be associated with conceptual difficulties that commonly occur in fluid mechanics. Previous studies have consistently reported that fluid concepts represent one of the most challenging topics in physics education. Hutasoit et al. (2025) identified numerous misconceptions related to hydrostatic pressure, Pascal's principle, buoyancy, and fluid equilibrium. Similar findings were reported by Atmaja and Samsudin (2024), who demonstrated that misconceptions frequently persist even after formal instruction and may interfere with students' ability to establish coherent conceptual relationships. Consequently, students may successfully answer questions involving isolated concepts while experiencing difficulties when required to integrate multiple principles simultaneously.

Evidence of such conceptual difficulties can also be found in studies focusing on static and dynamic fluids. Kurniawan (2023) reported that many students possess only partial understanding of static fluid concepts despite being able to apply formulas correctly. Likewise, Fatmawati et al. (2025) found that students often demonstrate adequate procedural competence while lacking deeper conceptual mastery. Similar concerns were expressed by Muki et al. (2025), who observed that students' understanding of fluid concepts frequently remains superficial and fragmented, particularly when instruction emphasizes mathematical procedures over conceptual reasoning.

The persistence of conceptual difficulties is not unique to Indonesian students. Koto and Ilhami (2023) reported that secondary school students continued to experience conceptual challenges in fluid dynamics even after participating in online learning during the pandemic. Furthermore, Putri et al. (2023) identified substantial misconceptions in dynamic fluid topics using a four-tier diagnostic test. These findings suggest that the challenges observed in the present study reflect broader patterns in physics learning rather than isolated classroom phenomena.

The substantial achievement gap between the upper and lower groups further highlights differences in conceptual understanding. Students in the upper group demonstrated near-complete mastery of the assessed concepts, whereas students in the lower group answered fewer than one-quarter of the items correctly. Such disparities indicate that conceptual understanding develops unevenly across learners. According to Hasan (2017), students operating at higher SOLO levels possess more interconnected cognitive structures, enabling them to interpret problems holistically. In contrast, students at lower SOLO levels tend to focus on isolated information and often fail to recognize conceptual relationships. The results of the present study strongly support this interpretation.

The item discrimination analysis provides additional evidence regarding students' conceptual profiles. Items with exceptionally high discrimination indices were generally associated with tasks requiring conceptual reasoning and integration. This finding aligns with Hartanti et al. (2021), who reported that higher-order SOLO items are particularly effective in differentiating students according to the complexity of their thinking processes. Similarly, Claudia et al. (2020) found that tasks requiring relational and extended abstract reasoning tend to reveal differences in conceptual understanding more clearly than tasks focused on simple recall.

From an educational perspective, the dominance of multistructural thinking indicates that instructional practices should place greater emphasis on deep learning approaches. According to Sabani et al. (2026), deep learning occurs when students actively construct relationships among concepts, evaluate evidence critically, and apply knowledge flexibly across situations. The findings suggest that many students have not yet reached this stage

because their understanding remains largely compartmentalized. Therefore, instructional interventions should focus on promoting conceptual integration rather than merely increasing factual knowledge.

Inquiry-based learning may represent a particularly effective strategy for addressing this issue. Damopolii et al. (2020) demonstrated that inquiry-oriented instruction significantly improves students' SOLO levels by encouraging them to investigate relationships among concepts and construct explanations independently. Such learning environments provide opportunities for students to engage in reasoning processes characteristic of relational and extended abstract thinking. Consequently, integrating inquiry activities, problem-based learning, conceptual discussions, and reflective questioning into physics instruction may facilitate students' progression toward higher SOLO levels.

The findings also have broader implications in the context of international educational assessments. The OECD (2023) PISA report highlighted that Indonesian students continue to experience difficulties in applying scientific knowledge to unfamiliar and complex situations. The dominance of multistructural responses observed in this study reflects a similar phenomenon. Students generally demonstrate adequate knowledge acquisition but encounter challenges when required to transfer and apply that knowledge in novel contexts. Therefore, strengthening higher-order thinking skills through conceptually oriented instruction remains a critical priority for science education.

Overall, the results indicate that the developed SOLO Taxonomy-based assessment instrument is capable of providing detailed information regarding students' conceptual understanding of fluid mechanics. The instrument not only measures achievement but also reveals the structural characteristics of students' thinking. The predominance of multistructural responses suggests that students possess substantial conceptual knowledge but still require support in integrating and extending that knowledge. Consequently, future instructional efforts should prioritize the development of relational and extended abstract thinking through inquiry-based, conceptually focused, and reflective learning experiences that encourage students to construct deeper and more transferable scientific understanding.

CONCLUSION

This study shows that the SOLO Taxonomy is effective for analyzing the quality of students' conceptual understanding of fluid concepts beyond simply determining correct or incorrect answers. The findings indicate that most students are at the multistructural level, meaning they can identify and use several relevant concepts but still have difficulty integrating them into a coherent conceptual framework. This suggests that students' understanding tends to reflect surface learning rather than deep learning. Therefore, physics instruction should emphasize activities that promote conceptual connections, reasoning, and higher-order thinking to help students achieve deeper levels of understanding. In addition, the results of this study can serve as a reference for teachers in designing more diagnostic assessments and for future researchers interested in applying SOLO Taxonomy-based analysis to other physics topics or educational contexts.

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