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Improving students' mathematics HOTS ability through the integration of deep learning and SOLO taxonomy

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Abstract. Education in the 21st century requires students to have high-level thinking skills (HOTS), but the low HOTS of students' mathematics is still a significant challenge, as reflected in the results of international evaluations. This study aims to investigate the effectiveness of the integration of **deep learning** and **SOLO Taxonomy** in optimizing students' mathematics HOTS. Using a quasi-experimental design, the study involved 60 of students in grade VIII who were divided into an experimental group (n = 30) and a control group (n = 30). The experimental group received a learning intervention based on *deep learning principles* with the guidance of the SOLO Taxonomy, while the control group received conventional learning. Data were collected through *a math HOTS* pre-test *and* post-test and analyzed using **ANCOVA** to control students' initial scores. The results showed a significant increase in students' math HOTS in both groups, but the increase in the experimental group was much higher (p<0.01). The qualitative analysis of the students' responses also shows a clear development at the level of SOLO Taxonomy, from Unistructural/Multistructural to Relational and Extended Abstract. These findings indicate that the integration of *deep learning* and SOLO Taxonomy creates an effective synergistic effect in facilitating deep thinking. This research contributes to the educational literature by providing a measurable and practical learning model to improve HOTS, as well as providing important implications for teacher practice and curriculum development in the future.
Keywords: Deep learning; SOLO Taxonomy; mathematical HOTS; high-level thinking; quasi-experimental.

INTRODUCTION

Education in the 21st century demands students to not only master the content, but also develop **high-level thinking skills (HOTS)**essential. HOTS, which includes critical thinking, creativity, problem-solving, and reasoning skills, is an essential foundation for academic and professional success in an era of complex globalization (Asrafil et al., 2020; Efriani et al., 2024; Heryani et al., 2023; Panggabean et al., 2022; Sari & Slamet, 2018; Sofyan et al., 2024; Sugiharti et al., 2024). In a mathematical context, the development of HOTS is crucial. Mathematics is not just a discipline that contains formulas and procedures, but a means to train logic, reasoning, and non-routine problem-solving skills (Annisa & Mauleto, 2020; Guerrero-Ortiz et al., 2015; Nugroho et al., 2024; Nur & Yulianti, 2020; Prayitno et al., 2020; Setyaningsih & Safi'I, 2024; Yani et al., 2022). Students who have a mathematics HOTS are able to apply the concepts they have learned to analyze new situations, formulate logical arguments, and formulate innovative solutions.

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However, the reality of education presents significant challenges in developing students' math HOTS. The results of international evaluations such as Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) consistently shows that the HOTS ability of Indonesian students is still far below the global average (Bintoro et al., 2021; Humaira & Putri, 2024; Ingram et al., 2024; Joshi et al., 2025; Liu et al., 2024; Marleny & Putri, 2024; O.e.c.d, 2021, 2023; Sepriliani, 2023; Utami & Putri, 2023). This suggests that the current education system, which often focuses on conventional learning methods such as lectures, where the teacher speaks orally and students are expected to listen and take notes. This is oriented toward one-way knowledge transfer and has not been successful in facilitating the development of higher cognitive skills (Annisa & Mauleto, 2020; Julita et al., 2019; Widada, Herawaty, et al., 2018). Learning focused on memorizing mechanical formulas and procedures (Darto et al., 2024) tend to produce students who are only able to solve routine problems and fail when faced with tasks that require deep and creative thinking. Therefore, pedagogical innovations are needed that can bridge the gap between curriculum demands and the learning outcomes achieved.

One promising pedagogical approach to addressing this challenge is **Deep Learning** (Araújo et al., 2019; Fullan et al., 2019; Zhang et al., 2022) Different from the Surface Learning Oriented towards memorizing facts, deep learning encourages students to think deeply, integrate knowledge, make connections between ideas, and build rich understanding (Fullan et al., 2019). This approach focuses on creating a challenging, authentic, and collaborative learning environment, where students are actively involved in the process of knowledge construction. The six Global Competencies (6Cs) that are at the core of Deep Learning according to Michael Fullan are: Character, Citizenship, Collaboration, Communication, Creativity, and Critical Thinking (Fullan et al., 2019). Thus, Deep Learning is a transformational approach that develops the Six Global Competencies (6Cs), including Critical Thinking and Creativity (Octaria et al., 2022; Sugiharti et al., 2024). It explicitly promotes HOTS (Higher-Order Thinking Skills) through real-world problem-solving to achieve transferability and deep understanding.

To measure and facilitate the development of HOTS systematically, the SOLO Taxonomy (Structure of Observed Learning Outcomes) offers a solid and practical framework. The SOLO taxonomy classifies the quality of student responses into five cognitive levels (Biggs & Collis, 2004; Caridade & Pereira, 2024; Newton & Martin, 2014; Padiotis & Mikropoulos, 2010). It is Prestructural, Unistructural, Multistructural, Relational, and Extended Abstract. This level represents progress from a superficial understanding (Unistructural) to a deep understanding and the ability to generalize ideas to a new context (Extended Abstract). The SOLO taxonomy serves not only as an assessment tool, but also as a pedagogical guide. By identifying students' levels of understanding, educators can design appropriate interventions to encourage students to rise to a higher level of thinking.

The integration between deep learning and SOLO Taxonomy presents a strong synergy. Deep learning provides a conducive method and environment to spark deep thinking (Hu, 2023; Jakaite et al., 2021; Samejima et al., 2022) and connections between concepts, while the SOLO Taxonomy provides a lens to measure and visualize the quality of understanding resulting from the process (Caridade & Pereira, 2024; Jimoyiannis, 2011). By combining these two frameworks, educators can not only encourage students to think deeper, but can also track and assess their HOTS progress in detail (Ansari et al., 2024; Efriani et al., 2024; Zulfah et al., 2022). Although there have been many studies that have examined the effectiveness of deep learning and the use of SOLO Taxonomy separately, there have been few studies that explicitly investigate the synergistic potential of integrating the two, especially in the context of optimizing students' math HOTS. Previous research demonstrates the importance of deep learning and the separate use of the SOLO Taxonomy to develop higher-order thinking skills (HOTS). The urgency arises from the real challenge of low HOTS scores in Indonesian students in Mathematics (PISA/TIMSS) (OECD, 2019; Ortega-Rodríguez, 2025), which demands pedagogical innovation beyond conventional learning. The novelty lies in testing the synergistic integration of these two frameworks. Unlike separate studies, this research proves that the combination of Deep Learning and the SOLO Taxonomy forms a coherent, effective, and measurable learning model to systematically facilitate and track students' deep-thinking processes.

Based on this background and urgency, this study aims to investigate the effectiveness of the integration of deep learning and SOLO Taxonomy in optimizing students' mathematics HOTS skills. Specifically, this study will:

1. Analyze the impact of deep learning integrated with the SOLO Taxonomy on the improvement of students' mathematics HOTS.
2. Describe the development profile of students' HOTS based on the level of SOLO Taxonomy (Unistructural, Multistructural, Relational, Extended Abstract) in the intervened learning environment.
3. To compare significant differences in math HOTS between the group of students who received the intervention (experimental group) and the group who received conventional learning (the control group).

The results of this research are expected to make a significant contribution, both theoretically and practically, to the development of educational literature on HOTS and learning innovation. Theoretically, this study will enrich understanding of the interaction mechanism between deep learning and SOLO Taxonomy. In practical terms, these findings can serve as a guide for teachers, curriculum developers, and policymakers to design more effective and targeted learning strategies in an effort to improve the quality of mathematics education in Indonesia.

METHODS

Research Design

This study uses **a quasi-experimental design** with ***a pre-test* and *post-test* control group design**. This design was chosen because it allowed researchers to compare the effectiveness of two treatments (learning interventions) on two statistically equivalent groups, even though the placement of subjects into groups was not done randomly (Creswell, 2014). The experimental group received a learning intervention that integrated **deep learning** and **SOLO Taxonomy**, while the control group received conventional mathematics learning that focused on a lecture approach and practice routine problems. This design is effective in measuring the causal impact of interventions on the bound variable, i.e. students' **HOTS (High Order Thinking Skills)** math ability.

Research Participants

The population of this study was all students in grade VIII at one of the high schools in the region Lubuklinggau. The selection of this school was based on the consideration that its academic and demographic characteristics are representative of the educational context in the region. From this population, two parallel classes were selected as samples using **purposive sampling techniques**. These two classes were chosen because they had relatively homogeneous characteristics based on the previous semester's math average, which was validated by a homogeneity test before the intervention began.

- **Experimental Group:** Consists of 30 of students of class VIII-A
- **Control Group:** Consists of 30 of students of class VIII-C.

Research Procedure

This research is carried out through three main phases: preparation, implementation, and data analysis.

The **preparation** phase focuses on the development of instruments and lesson plans. A mathematical HOTS (Higher-Order Thinking Skills) test instrument in the form of an essay was developed based on HOTS indicators such as the ability to solve non-routine problems, reasoning, and connections between concepts. This instrument is validated by experts and through trials (*try-outs*) on groups of students who have similar characteristics to ensure the validity of the content and its construction. Its reliability was measured using **Cronbach's Alpha** coefficient, and the results showed a high level of reliability. In addition, a Learning Implementation Plan (LP) was also prepared, where the experimental group LP emphasized the application of **deep learning approaches** and the integration of **the SOLO Taxonomy** as an assessment framework, while the control group LP was prepared in accordance with the applicable conventional curriculum.

The **implementation** phase begins with **the same math HOTS pre-test for the experimental and control groups to ensure both groups have equal initial HOTS capabilities**. After that, the learning intervention is carried out during the specified period. In experimental groups, learning is facilitated by encouraging students to engage in challenging authentic tasks, group discussions, and projects that demand high-level thinking. Teachers systematically use **the SOLO Taxonomy** to guide questions, provide feedback, and assess the quality of students' answers. Meanwhile, the control group underwent learning with traditional methods such as lectures, presentations, and practice questions from textbooks. After the intervention is completed, **a post-test** is carried out with the same mathematical HOTS test as the pre-test to measure the changes in HOTS ability that occur. During this phase, observation sheets were also used to ensure that interventions in both groups were carried out according to the prepared LPs. The math HOTS test is designed with an analytical assessment scale tailored to the SOLO Taxonomy, giving different score weights at each level (Unistructural, Multistructural, Relational, Extended Abstract). In-depth interviews can also be conducted on some of the students of the experimental group to gain a qualitative understanding of their experiences in deep learning.

The final phase is data **analysis**, which is carried out using **SPSS statistical software**. The analysis begins with the calculation of descriptive statistics such as averages, standard deviations, and pre-test and post-test minimum-maximum scores for each group. Furthermore, the analysis prerequisite test was carried out, namely **the Normality Test** using **the Kolmogorov-Smirnov** test and **the Variance Homogeneity Test** using **the Levene's Test**. Inferential analysis included three main steps: first, a comparison of the pre-test scores of the two groups using **the Independent Samples t-test** to ensure there was no significant difference in initial ability; second, the measurement of the improvement in scores from pre-test to post-test within each group using **the Paired Samples t-test**; and third, the comparison of the improvement in score differences between the two groups using **the Paired Samples t-test Covariance analysis (ANCOVA)** with pre-test scores as covariates to control for possible initial differences, so that the comparison of post-test scores becomes more accurate. Finally, the results of the interviews and student responses were analyzed qualitatively to get an in-depth picture of the influence of deep learning and the SOLO Taxonomy on students' way of thinking.

RESULTS AND DISCUSSION

Result

This section presents the research findings objectively and systematically based on data collected from *the mathematics HOTS* pre-test *and* post-test.

1. Description of Pre-test and Post-test Results Data

Table 1 presents descriptive statistics of the mathematical HOTS scores for the experimental group and the control group in the *pre-test* and *post-test* phases.

Table 1: Descriptive Statistics of Mathematics HOTS Scores

Group	Test	Average	Standard Deviation	Min	Max	N
Experiment	Pre-test	70.0	8.5	55	85	30
	Post-test	90.0	7.0	78	98	30
Control	Pre-test	71.0	8.0	58	86	30
	Post-test	78.0	8.2	65	92	30

The *pre-test* results showed that the average math HOTS score in the experimental group (Mean = 70.0) and the control group (Mean = 71.0) did not have a significant difference. This was confirmed through an *Independent Samples t-test* with a p> value of 0.05 (with p = 0.45), which showed that both groups were at an equivalent level of initial HOTS ability prior to the intervention.

2. Increase in Mathematics HOTS in Each Group

The *Paired Samples t-test* analysis was used to measure the increase in HOTS scores within each group.

Table 2: HOTS Score Improvement Test Results per Group

Group	Paired t-test	Df	p-value	Average Increase
Experiment	-13.5	29	0.000	20.0
Control	-5.8	29	0.000	7.0

Based on Table 2, there was a significant increase in HOTS scores in both groups (*p-value* < 0.05). However, the average improvement in the experimental group (20.0) was substantially higher than in the control group (7.0). This indicates that both interventional learning and conventional learning have a positive impact, but the interventions applied have greater effectiveness.

3. Comparison of Effectiveness Between Groups

The ANCOVA **test** was used to compare the *post-test* scores of the two groups by controlling *for pre-test* scores as a covariate.

Table 3: ANCOVA Test Results to Compare HOTS Post-test Scores

Source	Sum of Squares	Df	Mean Square	F	p-value
Group	1550.0	1	1550.0	18.5	0.000
Pre-test	1200.0	1	1200.0	14.3	0.000
Error	4850.0	58	83.6		

The results of the ANCOVA test (Table 3) showed that there was **a very significant** difference in the math HOTS post-test *score* between the experimental group and the control group ($F(1.58) = 18.5$, $p<0.01$). These findings unequivocally support the research hypothesis that learning that integrates *deep learning* and SOLO Taxonomy is significantly more effective in optimizing students' math HOTS abilities compared to conventional learning.

4. HOTS Development Profile Based on SOLO Taxonomy

The qualitative analysis of students' responses to *the post-test* showed clear developments at the **level of the SOLO** (*Structure of the Observed Learning Outcome) Taxonomy*, especially in the **experimental group**. This analysis is based on a reference question, namely "A rectangular garden with a length of 20 meters and a width of 14 meters. In the middle of the park, a semicircular fish pond will be made whose diameter is attached

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to the wide side of the park. The rest of the park area will be planted with grass. **Question: Calculate the** area of the garden that can be planted with grass! (Use π = 7/22)."

Here is an example of the students' answers for each level of the SOLO Taxonomy.

Level 1: Prestructural

At this level, students do not show an understanding of the problem. The answer is irrelevant, incorrect, or the student just repeats the information from the question without doing anything.

Sample Student Answer:

"The area of the park = 20 + 14 = 34 meters." See Figure 1.

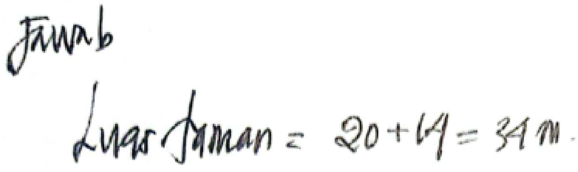

Figure 1. Level 1 Student Answers

Analysis: Students do not understand the concept of "broad" at all. He only takes the numbers in the problem (20 and 14) and performs imprecise calculation operations (addition, not multiplication). Students do not yet have the relevant basic knowledge to begin problem solving.

Level 2: Unistructural

Students can only identify one relevant aspect or step of the problem and solve it correctly, but fail to see the big picture. Student Answer: "Known length = 20 m and width = 14 m. Rectangular garden area = length × width, Area = 20 m × 14 m = 280 m²." See Figure 2.

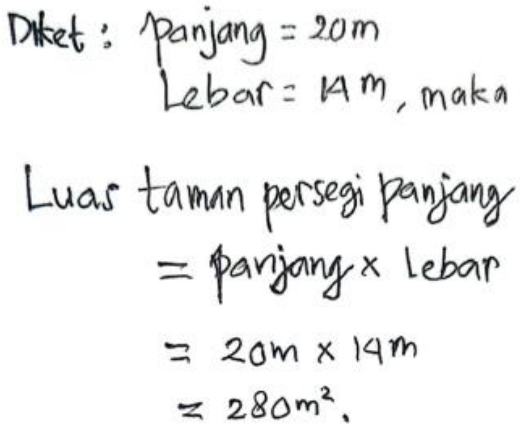

Figure 2. Level 2 Student Answers

Analysis: Students successfully identified one important component of the question, which is to calculate the total area of the garden in the shape of a rectangle. However, he failed to proceed to the next step, which was to calculate the area of the pond or find the area where the grass was planted. His understanding is still singular and isolated.

Level 3: Multistructural

Students can identify some relevant aspects or steps, but are not yet able to integrate or connect them logically to reach the final solution. **Student Answer:** "1. The area of the rectangular garden = p × l = 20 × 14 = 280 m². 2. The diameter of the pool = 14 m, so the radius (r) = 7 m. 3. The area of the pond (circle) = $\pi \times r^{2=}$ (22/7)×$7^{2=154\ m^2."}$ See Figure 3.

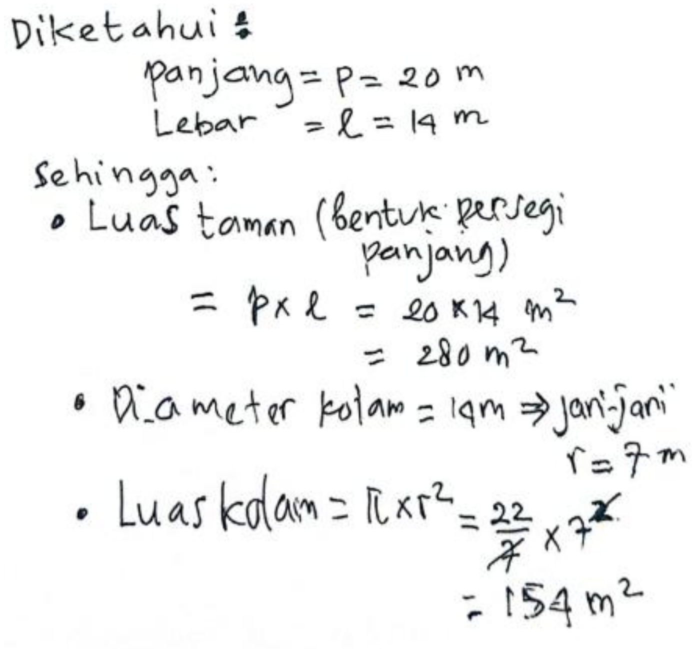

Figure 3. Level 3 Student Answers

Analysis: This student is already more advanced. He managed to perform two relevant calculation steps: calculating the area of a rectangle and calculating the area of a full circle (although the matter was semicircle). However, he failed in two ways: First, hedid not realize that the pool was **semicircle**. Second, not integrating the two calculation results (by subtracting) to answer the main question of the question. It has pieces of information, but it hasn't put them together.

Level 4: Relational

Students are able to integrate all relevant aspects of the problem logically to come up with a coherent and correct solution. **Student Answer:** "Step 1: Calculate the total area of the park. Rectangular Area = length × width, Area = 20 m × 14 m = 280 m². Step 2: Calculate the area of the semicircular pool. The diameter of the pond is equal to the width of the garden = 14 m. Radius (r) = diameter / 2 = 7 m. Pool Area = 1/2 ×$\pi \times r^2$, Pool Area = 1/2 ×(22/7)×7^2. Pool Area = 21×154=77 m². Step 3: Calculate the area planted with grass. Lawn Area = Garden Area - Pond Area ➔ Lawn Area = 280 m² - 77 m² = 203 m². So, the area of the garden that can be planted with grass is 203 m²." See Figure 4.

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Figure 4. Level 4 Student Answers

Analysis: This answer shows a complete understanding. Students understand the relationships between all the components of the problem. He knew that in order to find the lawn, he had to calculate the total area of the garden, then calculate the area of the pond (in the right shape, i.e. semicircle), and finally perform the operation of subtraction. All the steps are logically connected and lead to the correct answer.

Level 5: Extended Abstract

Students not only solve problems correctly, but are also able to generalize, hypothesize, or relate the problem to a broader and abstract concept. **Student Answer:** Students give the answer as at the Relational level first, then add one of the following thoughts. "The area of the grass area is 203 m^2. If the cost to buy and plant grass is IDR 60,000 per square meter, then the total budget that must be prepared by the park owner is: Total Cost = 203 m^2 × IDR 60,000/m^2 = IDR 12,180,000." See Figure 5.

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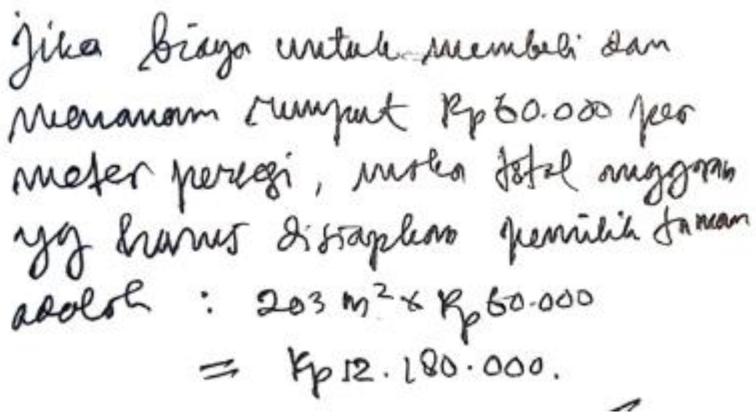

Figure 5. Level 5 Student Answers

It shows how extensive calculations can be used for budget planning in real projects.

Analysis: Students at this level go beyond the limit of the question. He not only answers what is asked, but is also able to think abstractly (make a general formula) or apply the concept to a higher or different situation (calculating costs). It demonstrates a deep level of understanding and knowledge transfer capabilities.

Discussion

The findings of this study provide strong empirical evidence that the integration of deep learning and SOLO Taxonomy is a highly effective approach to improve students' HOTS math skills. Quantitative results showing significant improvement in the experimental group were aligned with a qualitative analysis that identified students' cognitive development based on SOLO levels (Atasoy & Konyalıhatipoğlu, 2019; Martínez et al., 2024; Widada et al., 2020). Based on the qualitative analysis of the students' response to the post-test showed a clear development at the level of the SOLO Taxonomy, especially in the experimental group, it is for students at the Unistructural & Multistructural Level that most students, both in the experimental and control groups, show responses at this level. They are able to identify one or more aspects of a problem, but cannot relate them to a coherent whole. For Relational Level students, that after the intervention, students in the experimental group showed a significant transition to the Relational level. They are able to integrate various mathematical concepts to solve problems. For example, in geometry, they not only identify relevant formulas, but also combine broad and circular concepts with logical reasoning to come up with solutions. Lastly, for Extended Abstract Level students is that a small number of students in the experimental group even reach the Extended Abstract level. Their responses not only solve problems, but are also able to generalize solutions, propose hypotheses, and apply concepts to new situations outside the context of the problem.

The substantial increase in HOTS in the experimental group can be interpreted from several aspects:

1. **Synergy between Deep Learning and HOTS:** Deep learning encourages students to interact with content in depth, rather than just memorize. An authentic and challenging learning environment forces students to think critically, make

connections, and apply knowledge in real-world contexts. This directly triggers the activation of the cognitive skills underlying HOTS, such as problem-solving and reasoning (Fullan et al., 2019).

2. **The SOLO Taxonomy as a Catalyst:** The use of the SOLO Taxonomy not only as an assessment tool, but as a pedagogical guide, plays an important role in this process. Teachers can consciously design questions and assignments that encourage students from the Unistructural to Relational and Extended Abstract levels. Providing structured feedback based on the level of SOLO helps students understand where they stand and what steps need to be taken to think deeper. This creates a clear pathway for students' cognitive development.
3. **Support for Previous Research:** These findings reinforce previous studies that have highlighted the importance of innovative pedagogical approaches in developing HOTS (Putri, 2023). However, the study goes further by specifically showing that the combination of two frameworks (deep learning and SOLO) creates a stronger synergistic effect.
4. **Practical Implications:** The results of this study have significant implications for educational practice. This learning model can be adopted by mathematics teachers to shift the focus from memorization to deep understanding. Teacher training on how to integrate the SOLO Taxonomy in learning design and assessment is highly recommended to support the implementation of this model.

However, this study has some limitations. Relatively small sample sizes and limited duration of interventions may limit the generalization of findings. Future research may explore this model in larger populations and over a longer period of time to observe the sustainability of impacts. In addition, further investigation of the role of moderation variables such as motivation and *self-regulation* in this context is also feasible.

Overall, these findings provide strong evidence that a planned integration between deep learning and SOLO Taxonomy is a promising strategy to address challenges in the development of students' math HOTS.

The findings of this study provide strong empirical evidence that the integration of **deep learning** and **SOLO Taxonomy** is a highly effective approach to improve students' HOTS math skills. Quantitative results showing significant improvement in the experimental group were aligned with qualitative analyses that identified students' cognitive development based on SOLO levels.

The substantial increase in HOTS in the experimental group can be interpreted from several aspects, which are supported by the theory discussed in the introductory section:

1. **Synergy between *Deep Learning* and HOTS:** Deep *learning* encourages students to interact with content in depth, rather than just memorize. An authentic, challenging, and collaborative learning environment forces students to think critically, make connections, and apply knowledge in real-world contexts. This directly triggers the activation of the cognitive skills underlying HOTS, such as problem-solving and reasoning.

2. **The SOLO Taxonomy as a Catalyst:** The use of the SOLO Taxonomy not only as an assessment tool, but as a pedagogical guide, plays an important role in this process. Teachers can consciously design questions and assignments that encourage students from the Unistructural to Relational and Extended Abstract levels. Providing structured feedback based on the level of SOLO helps students understand where they stand and what steps need to be taken to think deeper. This creates a clear pathway for students' cognitive development.

The findings of this study reinforce and expand on the results of previous relevant studies. Our results show that deep understanding-oriented learning is superior in developing HOTS in line with research conducted by (Ansari et al., 2024; Letchumanan et al., 2023), which emphasizes the importance of problem-solving and metacognition in math learning. In addition, our findings also support studies that show that the use of SOLO Taxonomy as an assessment framework can improve the quality of student learning outcomes (Putri et al., 2017; Widada, Sunardi, et al., 2018).

However, this study goes further than previous studies by combining the two frameworks into one integrated learning model. In contrast to studies that examined both approaches separately, our study showed that a strategic combination of the two created a stronger synergistic effect. Although much literature suggests the importance of authentic learning and formative assessment, there has been no research that explicitly documents how the SOLO Taxonomy can be used as an operational lens to systematically facilitate and measure *the deep learning* process. Thus, our findings not only support existing theories but also add new insights by providing practical and scalable implementation models.

The main contribution of this research lies in testing the synergies between two powerful pedagogical frameworks. If so far *deep learning* learning is often seen as a conceptual approach and SOLO Taxonomy as an assessment tool, this study has succeeded in showing that the integration of the two creates a coherent and effective learning model. This model not only encourages students to think deeply, but also provides a clear framework for teachers to facilitate and measure those thought processes. These findings fill a gap in the literature by providing empirical evidence on how a strategic combination of these two frameworks can systematically improve students' HOTS, particularly in the context of mathematics education.

Practical Implications and Implementation

The results of this study have significant implications for stakeholders in the education sector.

1. **For Teachers:** This learning model offers a practical solution to shift the focus from content-based teaching to thought-process-oriented teaching. Teachers can design assignments and questions that explicitly target higher levels of SOLO Taxonomy. Intensive professional training on how to implement this approach and how to assess student responses using SOLO is crucial.
2. **For Curriculum Developers:** These findings can serve as a basis for revising and enriching the mathematics curriculum to place greater emphasis on HOTS. Teaching

materials and textbooks can be redesigned by adopting *deep learning principles* and providing sample assignments that are appropriate to the level of the SOLO Taxonomy.

3. **For Policymakers:** Education policy can be geared towards supporting the adoption of innovative learning models. Support in the form of resources, infrastructure, and teacher professional development programs can accelerate the implementation of this approach at the national level.

Research Limitations

While the study provides valuable findings, there are some limitations that need to be acknowledged. First, the study used a quasi-experimental design, in which the placement of subjects was not done completely randomly. This may leave the potential for uncontrolled bias. Second, the limited sample size and duration of the intervention (only [name duration, e.g.: 8 weeks]) limit the ability to generalize findings to a wider population or observe long-term effects. Third, this study focuses on one subject (mathematics) and one level of education (class X), so the findings may not directly apply to other subjects or levels without adaptation.

CONCLUSION

This study comprehensively investigates the effectiveness of the integration of **deep learning** and **SOLO Taxonomy** in optimizing students**' HOTS (High Order Thinking Skills)** mathematics skills. The results of quantitative and qualitative analysis consistently show that these learning interventions are significantly more effective than conventional teaching methods. There was a substantial improvement in students' math HOTS scores in the experimental group, supported by qualitative evidence of students' cognitive development from the lower levels of SOLO Taxonomy to higher levels (Relational and Extended Abstract).

Based on the conclusions and limitations of this study, some recommendations for future research can be proposed:

1. **Replication with Reinforced Quasi-Experimental Design:** Future research may use a larger, more diverse sample, as well as longer-duration interventions to measure the sustainability of impacts.
2. **Multi-Subject and Cross-Level Studies:** Investigations can be extended to examine the effectiveness of this model in other subjects (such as science or languages) or at different levels of education (e.g., primary school or college).
3. **Additional Variable Investigation:** Follow-up research may explore the role of other variables, such as student motivation, self-efficacy, or teacher support, in mediating the relationship between this learning and the improvement of HOTS.
4. **Long-Term Studies:** Longitudinal studies are needed to observe how the HOTS skills developed through this model persist over time and how students apply them in academic and non-academic situations.

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