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# Leveraging STEAM Learning and SOLO Taxonomy to Cultivate Deep Mathematical Understanding: A Conceptual Framework for Deep Learning in Primary Education

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**Abstract.** Mathematics proficiency among Indonesian primary school students remains below expectations, as reflected in the 2018 PISA results showing scores significantly below the OECD average. This study proposes a conceptual framework that integrates STEAM (Science, Technology, Engineering, Arts, and Mathematics) learning with the SOLO (Structure of Observed Learning Outcomes) Taxonomy to foster deeper mathematical understanding. Using a qualitative literature review approach, this research analyzes how both frameworks contribute to enhancing students' conceptual, procedural, and metacognitive skills. STEAM promotes interdisciplinary, project-based learning rooted in real-world contexts, while the SOLO Taxonomy provides a structured progression of cognitive complexity from surface learning to extended abstraction. Findings suggest that the integration of these approaches enhances meaningful engagement, supports creativity, and improves students' problem-solving abilities. This framework offers both theoretical and practical guidance for teachers in designing adaptive, transformative mathematics instruction aligned with 21st-century learning demands.

**Keywords**: *STEAM Learning, SOLO Taxonomy, Deep Mathematical Understanding, Deep Learning, Primary Education*

## 1. Introduction

In the educational context in Indonesia, mathematics mastery is a very important aspect that needs to be discussed in preparing an increasingly competitive generation up to the level of the world's community. Mathematics has never been merely about numbers or formulas for students but has always ensured the inculcation of critical thinking abilities, analytical skills, and problem-solving competencies necessary for day-to-day undertakings (Kuhlthau et al., 2015). Meanwhile, the reality of today proves that the mathematical ability of the Indonesian people, especially at the elementary school level, is still far below expectation. This has already been reflected in PISA 2018 wherein Indonesia earned a low ranking under mathematical literacy with an average score typecast at 379 way below OECD's average benchmark at 489 (OECD, 2019). This reflects a significant gap between expectations and reality in mathematics education in Indonesia.

The state of mathematical abilities among students in Indonesia clearly speaks of conceptual problems that are basic. Findings reveal a fact that students face difficulty in applying mathematics to real-life practical situations, especially under normal circumstances where conventional methods are used. Here, the term 'conventional' denotes teaching for memorization and not for understanding (Wahba et al., 2022). Pratiwi and Khotimah (2022) have further emphasized this method as a constraint on the ability of students to solve problems critically, which is highly demanded in learning nowadays. It thus highlights an urgent call of Innovative frameworks such as STEAM education that can be discussed having more scope to engage deeply with mathematics to cultivate success-related skills (Rozhana et al., 2023; Wahba et al., 2022).

The STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach is an integration methodology perceived to improve mathematical comprehension among learners by the fusion of art with science. It creates abilities in creativity and critical thinking which are prerequisites for effective problem-solving. Research has revealed that students who learn STEAM become more involved, have better motivation leading to improved learning outcomes specifically in mathematics (Alfayez 2024; Aguilera & Ortiz-Revilla, 2021). Teachers form positive attitudes toward the implementation of STEAM practices thus giving an indication of willingness to adopt this pedagogical innovation (Alfayez, 2024; Okwara & Pretorius, 2023). This collaborative approach also enhances one's understanding of mathematical concepts due to more profound interdisciplinary linkages through actual applications in real world scenarios (Henita et al., 2023; Quigley et al., 2017).

The STEAM approach in the teaching of mathematics at its best keeps learners busy with varied activities that underscore real-world relevance. Project-based learning encourages critical thinking and sharing experiences between learners by allowing them to probe mathematical concepts through designing and executing projects akin to practical applications. Some experiments can vividly express to learners the images and analysis of data by which mathematical principles are discovered. Problem-solving tasks emanating from daily life will always demonstrate the beautiful usefulness of mathematics in real terms, attracting students to apply their knowledge. Such an approach is multi-faceted and deepens mathematical understanding while fostering attributes such as creativity and communication among learners.

In addition to the STEAM approach, the application of the SOLO (Structure of Observed Learning Outcomes) taxonomy in mathematics education is potential to enhancing metacognitive skills and fostering deep understanding among students. By progressively guiding learners through various levels of cognitive complexity branging from basic understanding to applied problem-solving the SOLO taxonomy provides a structured framework for assessing and developing student competencies in mathematics (Ghunaimat & Alawneh, 2024). For instance, it has been shown that effectively using the SOLO taxonomy can improve students' grasp of key mathematical concepts, such as coordinate geometry (Caniglia & Meadows, 2018). Moreover, incorporating the SOLO framework encourages pre-service teachers to reflect on their pedagogical strategies and adapt their teaching methods accordingly, promoting deeper engagement and critical thinking in mathematics education (Setyowati et al., 2020; Nuringtyas & Yunianta, 2019).

Despite the significant potential in integrating the STEAM approach and the SOLO taxonomy, there is still limited research exploring and attempting to implement these two approaches simultaneously in the context of mathematics education in Indonesia. This study aims to fill that gap by offering a conceptual framework that can be used to enhance students' mathematical understanding at the elementary school level. Thus, this research not only contributes to the development of educational theory but also provides practical solutions that can be applied in the field.

The importance of this research lies in its ability to bridge the gap between theory and practice in mathematics education. By adopting the STEAM approach and the SOLO taxonomy, it is hoped that students will not only understand mathematical concepts deeply but also be able to apply them in everyday life. This research is expected to make a significant contribution to the development of more effective curricula and teaching strategies in Indonesia.

In addressing the challenges in mathematics education in Indonesia, the STEAM approach and the SOLO taxonomy offer innovative and effective solutions. By integrating these two approaches, it is hoped that students can develop a deeper understanding of mathematical concepts and be able to apply them in everyday life. This research is expected to make a significant contribution to the development of more effective curricula and teaching strategies in Indonesia, as well as bridge the gap between theory and practice in mathematics education.

## 2. Method

This study utilizes a literature review methodology with a qualitative approach to explore and analyze relevant literature regarding the implementation of the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach and the SOLO (Structure of Observed Learning Outcomes) taxonomy in mathematics education at the elementary school level. The data sources used include journal articles, books, research reports, and educational policy documents related to both approaches. The instruments employed in this research consist of a literature analysis guideline designed to identify key themes, concepts, and findings from the various sources examined. The data analysis technique is conducted through content analysis, where the data obtained from the literature review is organized and categorized into relevant themes to identify conceptual definitions, operational definitions, integration patterns, contributions, and other aspects that can theoretically reveal the potential of implementing the STEAM approach and the SOLO taxonomy in enhancing deep mathematical understanding among Indonesian students.

## 3. Results & Discussion

As a result of this study, the key theme that emerges is the strategic integration of STEAM pedagogy and the SOLO Taxonomy as a coherent framework to cultivate deep mathematical understanding based on a synthesis of the literature for each variable.

### a. STEAM Education on Mathematic Learning

STEAM education emerges from society's growing need for versatile, multifaceted talent and has evolved through the successive frameworks of STS → STEM → STEAM, forming a richly layered interdisciplinary research oriented educational model (Maria et al., 2024).

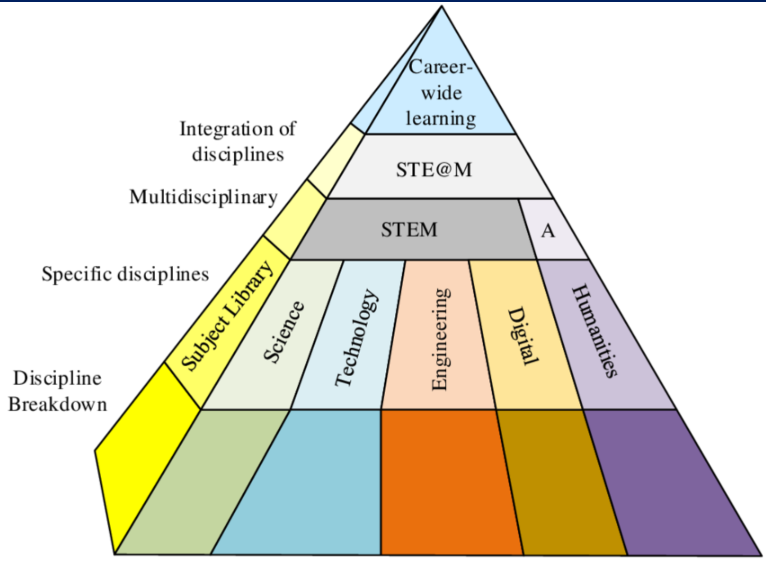


**Figure 1. STEAM Education Concept Pyramid**
(Source: Dong & Ran, 2024)

STEAM pedagogy thrives on merging distinct fields into a unified approach, prompting learners to tackle authentic challenges through open-ended inquiry and leverage the engineering design cycle to craft innovative, versatile solutions. Rather than abstract drills, STEAM begins with real-world scenarios, organizing learning around problem or project-based investigations. This model prioritizes active, hands-on engagement students immerse themselves in practical experimentation and exploration, weaving together insights from science, technology, engineering, art, and mathematics to construct integrated knowledge during each learning activity (Dong & Ran, 2024).

The integration of STEAM (Science, Technology, Engineering, Arts, and Mathematics) education into mathematics learning has emerged as a dynamic framework aiming to enhance student engagement, learning outcomes, and the development of 21st-century skills. According to Martín-Cudero et al., systematically reviewing mathematics education under a STEAM approach reveals that this pedagogical model allows for deeper learning experiences, emphasizing collaboration and integration across disciplines, which enhances the overall understanding of mathematical concepts Martín-Cudero et al. (2024). This integrated approach not only encourages critical thinking and problem-solving skills but also fosters creativity among students engaged in STEAM activities, as further evidenced by Lee et al., who argue that environments such as makerspaces facilitate active participation and creativity, particularly beneficial for learners struggling with traditional methods of mathematics and science (Bertrand & Namukasa, 2022).

The application of STEAM education in mathematics aligns closely with pedagogical models focused on inquiry-based learning. Bertrand and Namukasa advocate that a well-structured STEAM curriculum fosters rich interdisciplinary connections, enabling students to grasp complex mathematical ideas in context (Bertrand & Namukasa, 2022). The interplay between mathematics and other STEAM disciplines allows for a more holistic learning experience, one that is shown to significantly improve students' analytical skills and creativity, increasing engagement through meaningful real-world applications (Ismiati, 2024; Shen et al., 2021). Specifically, integrating mathematics with arts within STEAM contexts encourages learners to approach problems from multiple perspectives, thus reinforcing the transdisciplinary nature of learning that is essential in today's complex environment (Bertrand & Namukasa, 2020; Tsurusaki et al., 2017).

## b. A SOLO (Structure of Observed Learning Outcomes) Taxonomy

The SOLO (Structure of Observed Learning Outcomes) taxonomy is an educational framework developed by John Biggs and Kevin Collis that categorizes learning outcomes based on the complexity of students' understanding. It comprises five hierarchically structured levels: pre-structural, uni-structural, multi-structural, relational, and extended abstract. Each level reflects a progression in cognitive engagement, from basic recall of facts to the ability to synthesize information and apply knowledge in new contexts (Arceo 2024; Irvine, 2021). This taxonomy provides a clear description of students' learning achievements and facilitates the development of teaching strategies that encourage deeper learning and foster metacognitive awareness among learners (Tampi et al., 2017).

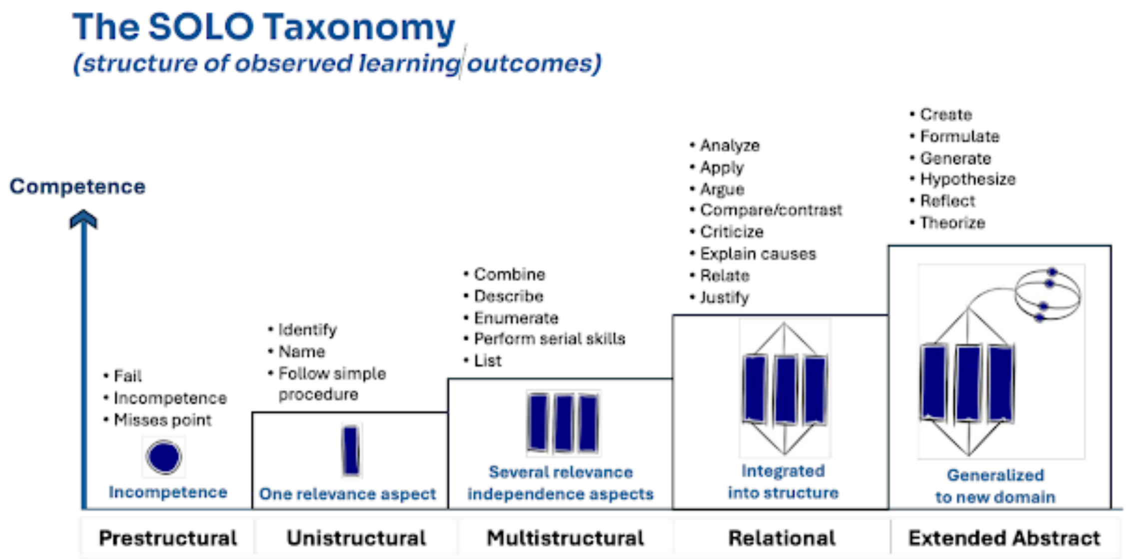


**Figure 2. The SOLO Taxonomy**

(Source: https://www.johnbiggs.com.au/academic/solo-taxonomy/)

In the SOLO Taxonomy, there are five levels of understanding that illustrate the progression of students' knowledge. At the pre-structural level, students display a limited understanding of a subject, often providing responses that reflect confusion or irrelevance, and they lack significant knowledge about the topic. The uni-structural stage, learners grasp a single relevant aspect of the concept, demonstrating basic recognition but failing to make connections between different ideas or elements. At the multi-structural level, students can identify and articulate multiple independent aspects of the topic; however, their knowledge lacks integration, resulting in isolated facts rather than a cohesive understanding. Progressing to the relational level, learners are able to connect and integrate various elements, showing an understanding of how different aspects relate to one another while applying their knowledge in meaningful contexts. Lastly, at the extended abstract level, students reach the highest tier of the taxonomy, where they can generalize knowledge across different situations, create new hypotheses or perspectives, and demonstrate critical thinking and creativity.

Studies have indicated that implementing the SOLO taxonomy in mathematics instruction can enhance students' problem-solving capabilities, metacognitive awareness, and critical thinking skills, making it a valuable tool in the mathematics education landscape (Hastari et al., 2021; Dong & Zhang, 2024). The SOLO taxonomy categorize the quality of learning outcomes based on students' cognitive development in educational settings, including mathematics. Each level reflects a progression in students' understanding, beginning with limited knowledge and evolving towards complex reasoning and abstraction. The taxonomy facilitates educators in assessing and fostering deep learning by emphasizing the relationships among concepts and promoting higher-order thinking skills.

### c. Deep Mathematical Understanding

Deep understanding in mathematics encompasses both conceptual and procedural knowledge, forming a critical foundation for effective learning and problem-solving. Conceptual understanding refers to the comprehension of mathematical concepts, operations, and relations, while procedural knowledge pertains to the ability to apply algorithms and procedures effectively. A deep understanding is integral for students to solve diverse mathematical problems and transfer their knowledge to various contexts (Hussein, 2022; Yuliandari & Anggraini, 2021). Based on various conceptual studies, the concept of a deep understanding of mathematics that is quite relevant in this context is as follows:

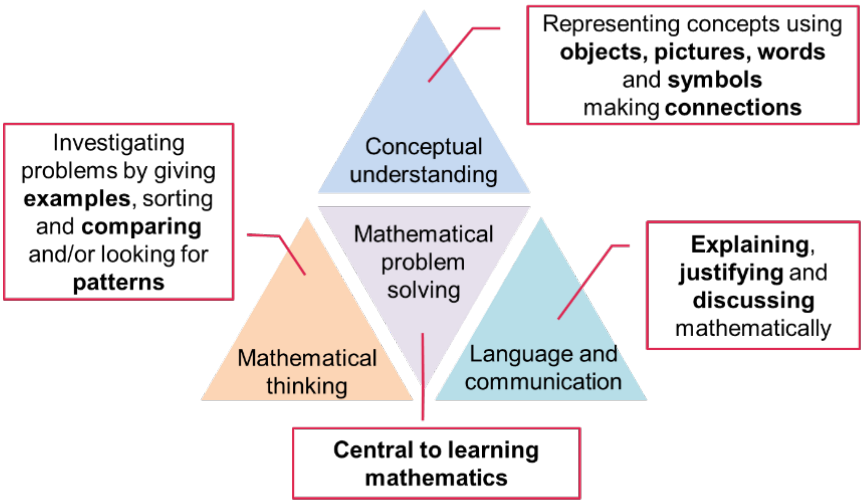


**Figure 3. Triangular Dimensions of Deep Mathematical Understanding**
(Source: https://www.ridgeway.staffs.sch.uk/curriculum/maths/)

This tripartite framework directly mirrors the dimensions of deep mathematical understanding, as articulated by Hiebert and colleagues: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and productive disposition (Arceo, 2024). In our diagram, Conceptual Understanding supplies the richly connected knowledge of mathematical objects and relations that underpins genuine insight, while Mathematical Thinking embodies both *strategic competence* the ability to formulate, implement, and reflect on solution plans and *adaptive* *reasoning*, the logical justification of each step. Language & Communication then becomes the vehicle for externalizing and refining thought through argumentation, critique, and representation, reinforcing *productive dispositions* by fostering confidence and intellectual engagement (Setyowati et al., 2020). Mathematical Problem Solving sits at the center not merely as a task but as the crucible in which these elements coalesce: learners draw on their deeply held concepts, deploy flexible procedures, select and adapt strategies, and articulate their reasoning to collaboratively construct robust understanding. Thus, deep mathematical understanding emerges only when conceptual networks, procedural skills, higher-order thinking, and communicative practices are developed in concert, each reinforcing the others in a continuous cycle of sense-making and reflection.

This triangular framework of mathematical competence can be interpreted through the lens of the SOLO taxonomy to scaffold the journey toward deep mathematical understanding: at the pre-structural level learners lack stable conceptions, struggle to engage coherent strategies, and cannot yet articulate mathematical ideas; moving into uni-structural, they grasp a single element recognizing one concept (Conceptual Understanding), executing an isolated procedure (Mathematical Thinking), or naming a term (Language & Communication); at multi-structural**,** they accumulate several discrete facts and skills knowing fractions, decimals, and basic operations separately without integrating them; ascending to relational, the three domains converge as learners form interconnected conceptual networks (seeing how fractions relate to ratios), select and monitor multi-step strategies, and use precise mathematical language to explain their reasoning, thereby solving non-routine problems coherently; finally, at extended abstract, students extend and generalize their integrated understanding inventing new solution methods, formulating proofs, and modeling novel contexts demonstrating deep mathematical understanding through the seamless interplay of rich concepts, adaptive thinking, and sophisticated communication.

### d. A Framework for STEAM Learning Aligned with the SOLO Taxonomy in Mathematics Instruction

The integration of STEAM learning with the SOLO Taxonomy offers a structured and engaging approach to enhance mathematical understanding in primary education. While STEAM provides real-world, creative contexts, the SOLO framework helps map the progression of student thinking. The following matrix outlines how these two approaches can be combined to guide learning activities and assessments across different levels of student understanding.

**Table 1. Matriks Framework Integration of STEAM-SOLO Taxonomy**

| SOLO Taxonomy Level | Characteristics of Student Understanding | STEAM Learning Activities & Focus | Assessment Strategies (Aligned with SOLO) |
|---|---|---|---|
| **Pre-structural** | - Limited understanding<br>- Confusion<br>- Irrelevant responses<br>- Lack of basic knowledge | **Focus:** Intro to basic concepts, vocabulary, tools<br>**Activities: S/T/E/A/M:** Simple observation (e.g., identifying shapes) Basic counting with | Observe engagement and responses<br>Ask "What is this?" or "Can you find…?"<br>Identify misconceptions or |

| SOLO Taxonomy Level | Characteristics of Student Understanding | STEAM Learning Activities & Focus | Assessment Strategies (Aligned with SOLO) |
|---|---|---|---|
| | | manipulatives<br>Recognizing numbers<br>**Math Focus:** Number & shape recognition• Simple sorting | missing understanding |
| **Uni-structural** | - Grasps one relevant aspect<br>- Basic recognition<br>- No connections between ideas | **Focus:** Understanding one idea or procedure<br>**Activities:**<br>**S/T/E/A/M:** Measure one object's length<br>Identify a material<br>Follow one design step<br>**Math Focus:**<br>Counting, identifying shape<br>Single operation (e.g., 2 + 3) | Ask "What is X?" / "How do you do Y?"<br>Recall of facts or steps<br>Example: "What is the perimeter of this square?" |
| **Multi-structural** | - Recognizes multiple elements<br>- Knowledge not yet integrated<br>- Lists facts or steps | **Focus:** Handling multiple components<br>**Activities:**<br>**S/T/E/A/M:** Measure all sides, list material properties• Build patterns, identify machines<br>**Math Focus:**<br>Calculate perimeter & area separately<br>Multi-step arithmetic<br>Identify polygons | Ask "What are parts of X?" / "List ways to do Y"<br>Perform unconnected procedures<br>Example: "Calculate area and perimeter of a rectangle." |
| **Relational** | - Connects and integrates ideas<br>- Applies knowledge meaningfully | **Focus:** Solve problems, explain relationships<br>**Activities:**<br>**S/T/E/A/M:** Design structures with math constraints<br>Analyze experiments<br>Explain gear systems<br>Geometric art<br>**Math Focus:**<br>Solve composite shape problems<br>Explain formulas<br>Convert between number forms | Ask "How does X relate to Y?" / "Why does Z happen?"<br>Assess integration and problem solving<br>Example: "If a square side doubles, how does area change?" |

Integrating STEAM learning with the SOLO Taxonomy in primary mathematics offers a structured approach to differentiated instruction and deepens student understanding through interdisciplinary engagement. By aligning activities with levels of cognitive development from pre-structural to extended abstract teachers can scaffold learning experiences that build progressively from foundational skills to complex, integrative thinking. STEAM contexts such as engineering tasks, artistic design, and scientific exploration provide real-world relevance, making mathematical concepts more engaging and meaningful. This approach encourages students not only to recall and apply knowledge but also to connect, analyze, and create cultivating critical thinking, problem-solving, and innovation. Assessment practices are likewise enhanced, shifting from right-or-wrong checks to evaluations that capture the depth and quality of student reasoning at each stage. Moreover, this integration supports inclusive and equitable learning by offering multiple access points to mathematical understanding, tailored to diverse student strengths and learning styles. It fosters creativity, autonomy, and a growth mindset, especially at the higher SOLO levels where students design solutions, develop models, and explore original ideas. Teachers benefit from a coherent framework for curriculum planning, allowing for collaborative, interdisciplinary instruction that connects mathematical learning with real-life application. Ultimately, this model not only improves conceptual mastery in mathematics but also prepares students to be adaptive, reflective thinkers in a complex and dynamic world.

Teachers or educators should consider several key terms and conditions when implementing the integration of STEAM learning and SOLO Taxonomy to ensure effective outcomes in deep mathematical understanding. First, they must establish clear learning objectives that align with both the curriculum standards and the specific goals of the STEAM activities, ensuring that all tasks are purposeful and relevant. Second, they should create a supportive classroom environment that encourages risk-taking and values mistakes as learning opportunities, fostering a growth mindset among students. Third, it is essential to differentiate instruction based on students' varying abilities and learning styles, providing appropriate scaffolding and resources to meet individual needs. Additionally, teachers should implement ongoing formative assessments to monitor student progress and adjust instruction as necessary, ensuring that students are engaged and challenged at the right level. Finally, collaboration among educators from different disciplines is crucial for sharing expertise and resources, which can enhance the quality of the learning experience and promote interdisciplinary connections. By adhering to these terms and conditions, educators can create a robust framework that supports deep mathematical understanding through the integration of STEAM and SOLO Taxonomy.

## 4. Conclusion

This study concludes that integrating STEAM pedagogy with the SOLO Taxonomy holds strong potential to enhance deep mathematical understanding at the primary education level. STEAM offers a dynamic, real-world learning environment that fosters creativity, motivation, and interdisciplinary problem-solving through hands-on and project-based activities. Simultaneously, the SOLO Taxonomy provides a structured cognitive framework to support students' progression from basic recall to advanced reasoning, synthesis, and application. When combined, these approaches promote the simultaneous development of conceptual understanding, strategic thinking, and mathematical communication.

Practically, the proposed framework equips educators with a clear guide for designing differentiated and progressive mathematics instruction, while also providing assessment strategies tailored to various levels of student understanding. This model supports the creation of inclusive, engaging, and meaningful learning experiences that respond to the challenges of low mathematics literacy in Indonesia. By bridging theory and practice, the integration of STEAM and SOLO not only contributes to educational research but also presents actionable solutions for curriculum development aimed at fostering 21st-century competencies in young learners.

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