

SOLO TAXONOMY IN MEDICAL EDUCATION

Abstract

The Structure of the Observed Learning Outcome (SOLO) taxonomy offers a comprehensive model for evaluating the depth and complexity of student understanding, making it particularly pertinent to the evolving landscape of medical education. This monograph examines its significance and contextual applicability, outlining its historical roots and evolution while emphasizing its relevance within contemporary educational frameworks. It delves into the pros and cons of SOLO taxonomy as discussed in current literature, illustrating its strengths in structuring assessments and learning outcomes, while acknowledging criticisms and limitations. The role of SOLO in a systems-based approach to medical education is examined, followed by a review of global studies that have employed this taxonomy in curriculum planning and evaluation. Special focus is given to the practicalities and potential of implementing SOLO taxonomy in the Indian medical education landscape, taking into account local constraints and opportunities. The monograph also presents insights into the emerging role of artificial intelligence in applying SOLO taxonomy effectively, offering possibilities for automated analysis and adaptive learning. A comparative discussion with other educational taxonomies provides clarity on its unique position and potential synergies. The monograph concludes with reflections on the future prospects of SOLO taxonomy as a tool to enhance teaching-learning processes and align educational goals with measurable learner outcomes in medical education.

Authors

Dr. Harshavardhan Balaganesan

MBBS., MD., MHPE

Assistant Professor,

Department of Radiodiagnosis,

Shri Sathya Sai Medical College and

Research Institute,

Sri Balaji Vidyapeeth, Puducherry.

Prof. (Dr.) K. R. Sethuraman

Endowed Chair,

Institute of Health Professions Education,

Sri Balaji Vidyapeeth, Puducherry.

I. IMPORTANCE AND RELEVANCE

Solo Taxonomy is a hierarchical model that is suitable for measuring learning outcomes of different subjects, levels and for all lengths of assignments ⁽¹⁾. It is a hierarchical model of increasing structural complexity; increasing consistency, increasing number of organizing dimensions and increasing use of relating principles ⁽¹⁾.

The SOLO taxonomy holds significant relevance in medical education for the several reasons including Depth of Understanding, Clear Learning Progression, Differentiation and Personalization, Metacognition and Reflection, Alignment with Higher Education Goals, Assessment and Feedback. It places a strong emphasis on assessing the depth of understanding and cognitive complexity of learning outcomes. It goes beyond surface-level knowledge and focuses on the ability to apply knowledge, think critically, and making relatable connections. This is crucial for developing higher-order thinking skills and preparing students for real-world challenges.

The taxonomy provides a clear learning progression with distinct levels of understanding. It offers a systematic framework for educators to identify and assess the stages of students' learning, allowing for effective instructional planning, personalized learning experiences, and targeted feedback.

The SOLO taxonomy allows for differentiation and personalization of learning experiences. It recognizes that students may be at different levels of understanding and provides a framework for tailoring instruction to meet individual needs. This promotes inclusive education and ensures that students are appropriately challenged and supported in their learning journey.

The taxonomy promotes metacognition, which involves students reflecting on their own thinking and learning processes. By using the SOLO taxonomy, students can develop a deeper awareness of their current level of understanding, set goals for improvement, and monitor their progress. This metacognitive approach enhances self-regulated learning and fosters lifelong learning skills.

The SOLO taxonomy aligns well with the goals of higher education, which aim to develop critical thinking, problem-solving, and analytical skills. By focusing on cognitive complexity and deep understanding, the taxonomy prepares students for academic success and professional growth.

The taxonomy provides a structured framework for designing assessments and providing meaningful feedback to students. It helps educators develop assessments that go beyond rote memorization and measure students' ability to analyse, evaluate, and create. The taxonomy also facilitates targeted feedback that guides students' progression, supports their learning goals, and informs instructional decision-making.

The SOLO taxonomy can be used (Using systems approach)

- At the input level
 - Aligning the curricula with assessments for verifying program objectives
 - Sensitizing Teachers from lesson planning to assessments
 - Inclusion in the orientation programs
 - Study materials based on the SOLO taxonomy
- At the Process level
 - Asynchronous – Students reflection on what they are learning
 - Synchronous – Assessments conducted for the students
- At the output level
 - Students to self-assess the knowledge gained
- At the Feedback level

II. BRIEF HISTORY

The SOLO taxonomy of learning proposed by Biggs and Collis in 1982 is a mechanism to motivate students' development intrinsically and extrinsically, to think reflectively and drive their self-determination to learn. SOLO taxonomy is a process used to describe increasing levels of complexity in a learner's understanding of a concept. SOLO taxonomy is a five-level approach that classifies the observed learning outcome as either prestructural, unistructural, multistructural, relational, or extended abstract.

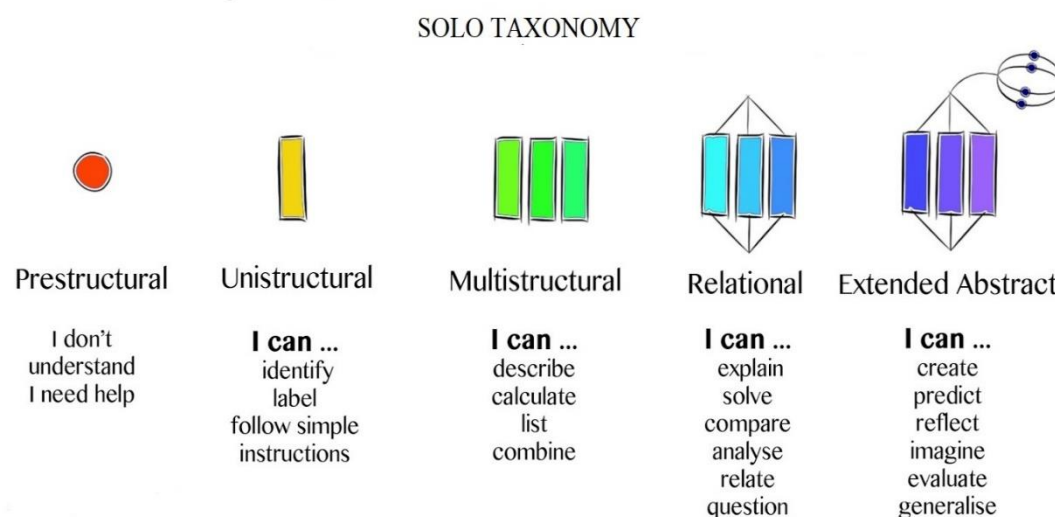


Figure 1: SOLO Taxonomy

The SOLO (Structure of Observed Learning Outcome) taxonomy was developed by educational psychologist John Biggs and Kevin. The taxonomy was primarily designed as a framework for assessing and understanding the levels of understanding demonstrated by learners.

The development of the SOLO taxonomy was influenced by earlier taxonomies, such as Bloom's taxonomy, which focused on cognitive learning domains. However, Biggs recognized the need for a taxonomy that specifically addressed the structure of learning outcomes and provided a clearer framework for assessing the depth of understanding.

Biggs drew inspiration from the work of Marton and Saljo, who had conducted research on the concept of "deep" and "surface" approaches to learning. Marton and Saljo's research suggested that students who engaged in deep learning focused on understanding concepts and making connections, while those who used surface learning focused more on memorization and reproducing information.

With these insights in mind, Biggs and Collis developed the SOLO taxonomy to capture the different levels of understanding and learning outcomes demonstrated by students. The taxonomy was based on a hierarchical structure that categorized levels of understanding from surface-level knowledge to deep understanding and application.

The SOLO taxonomy consists of five levels:

1. **Prestructural:** The learner has incomplete understanding or no relevant knowledge of the topic. Here the learner acquires unconnected pieces of information and is unsure about the subject matter in general.
2. **Unistructural:** The learner has a basic understanding of one aspect or element of the topic. Here the learner possesses an idea about the information and begins to make simple connections between information and ideas but no significant associations are formed.
3. **Multistructural:** The learner has a basic understanding of multiple independent aspects or elements of the topic. Here the learner begins to make several connections among individual ideas and information, but a meta-connection among all the information is lacking.
4. **Relational:** The learner can connect and integrate multiple aspects or elements of the topic to demonstrate a deeper understanding. Here the learner begins to see the connections between the individual parts of the information acquired and how they fit into the whole understanding of the concept.
5. **Extended Abstract:** The learner can generalize and transfer knowledge to new situations, apply principles, and think creatively about the topic.

As a learner moves along these levels, their cognitive abilities transition from that of recalling bits of information to evaluating and synthesizing information, ultimately supporting the transfer of knowledge acquired to new situations. This process of transforming knowledge demonstrates a deeper level of learning ⁽²⁾. The SOLO taxonomy gained popularity among educators and researchers for its ability to provide a more explicit and structured framework for assessing the depth of understanding demonstrated by students. It allowed educators to design assessment tasks that aligned with specific levels of understanding and provided a clearer picture of students' learning progression.

Over the years, the SOLO taxonomy has been widely used in various educational contexts, including K-12 schools and higher education. It has been applied to assess learning outcomes, design curriculum, guide instructional practices, and provide feedback to students. The taxonomy's focus on understanding and cognitive complexity has contributed to its enduring relevance in educational research and practice.

III. ORIGIN AND INITIAL EXPERIENCE

Learning is evaluated in the form of quantity and quality. Marton in the year 1976, pointed out that most of the practice has concentrated on quantity while neglecting attempts to assess learning quality. Assessing learning quality has been very subjective. Marton proposed a generalized levels to measure learning quality that coincided with Biggs's work in the year 1976 on applying Piagetian Psychology to the classroom which evolved into the taxonomy to measure learning quality called as Structure of the Observed Learning Outcome on 1978 ⁽³⁾. This was developed for school students and then introduced to undergraduate education.

John Biggs created the SOLO taxonomy to categorise student responses into five levels: Prestructural (lowest level), Unistructural, Multistructural, Relational, and Extended Abstract (highest level). This system was based on Piaget's different cognitive stages of development ⁽¹⁾.

Researchers suggested that by using the SOLO taxonomy, curricula can be aligned to assessments and verify program outcomes (Biggs and Collis, 1982). Biggs was a professor at the University of New South Wales in Australia and Collis was a senior lecturer at the University of Hong Kong. The alignment and validation of a program's curricular map using the SOLO taxonomy has been termed "constructive alignment". Constructive alignment is an example of outcome based education. In the constructive alignment approach, students are required to demonstrate an action such as "apply" or "perform" in the outcome statement. Subsequently, learning is assessed on the basis of the action taken by the student to reach the stated outcome. Thus, in the constructive alignment approach, the action taken by the student, not their ability to restate information, implies learning. The traditional learning activity of dissecting a human body that is still used in many medical schools today is an example of a constructive alignment approach because in the anatomy laboratory, students dissect structures and then demonstrate them to faculty and their classmates ⁽²⁾.

The development of the SOLO taxonomy was influenced by Biggs' research on student learning and assessment. Biggs was interested in understanding the different levels of understanding demonstrated by learners and how to effectively assess and promote deep learning.

The initial experience of using the SOLO taxonomy involved research studies and collaborations between Biggs and Collis. They carried out studies to look at the taxonomy's applicability and efficiency in various educational contexts.

The findings from these early studies and collaborations demonstrated the utility and potential of the SOLO taxonomy. It was found that the taxonomy provided a clear and structured framework for assessing and understanding the depth of student learning outcomes. Educators and researchers appreciated its ability to differentiate between different levels of understanding and guide instructional practices.

As the SOLO taxonomy gained recognition and acceptance in the educational community, it started to be adopted by educators in various countries. Its use expanded beyond higher education to K-12 schools and other educational settings.

Over time, educators and researchers continued to explore and refine the application of the SOLO taxonomy. They developed resources, guidelines, and practical strategies for implementing the taxonomy in curriculum design, assessment, and instructional planning. Today, the SOLO taxonomy remains a widely used and respected framework for assessing and promoting deep learning outcomes. Because it enables the evaluation of not only the acquisition of knowledge but also the depth of understanding and application of medical concepts, the SOLO taxonomy is particularly helpful in medical education. It helps educators and assessors evaluate the cognitive complexity and critical thinking skills of medical learners.

In medical education, the SOLO taxonomy can be used to design assessment tasks that go beyond simple recall of information.

The SOLO taxonomy also offers a framework for assessing how learners' knowledge and abilities have changed over time. It allows educators to identify areas of strength and areas that need improvement in medical students' knowledge and clinical reasoning abilities.

Overall, the SOLO taxonomy offers a valuable tool for assessing and promoting deep learning in medical education, supporting the development of competent and reflective healthcare professionals.

The following is an example with a single question and sample answers aligned with each level of the SOLO (Structure of Observed Learning Outcome) taxonomy in the context of radiology:

Question: Explain the concept of image resolution in radiology.

Level 1: Prestructural

Answer: "I don't know what image resolution means in radiology."

Level 2: Unistructural

Answer: "Image resolution in radiology refers to the clarity and level of detail in an image."

Level 3: Multistructural

Answer: "Image resolution in radiology is influenced by factors such as pixel size, spatial frequency, and image noise. Higher resolution images have smaller pixels and can display finer details."

Level 4: Relational

Answer: "In radiology, image resolution affects the ability to detect and differentiate small structures or pathologies. Higher resolution allows for better visualization of fine anatomical details, aiding in accurate diagnosis and treatment planning. However, increasing resolution

may also increase radiation dose or image acquisition time, necessitating a balance between image quality and patient safety."

Level 5: Extended Abstract

Answer: "Image resolution in radiology is a crucial aspect that impacts the quality and diagnostic value of medical images. It involves a trade-off between spatial resolution (detail) and noise. Radiologists strive to achieve optimal image resolution to enhance diagnostic accuracy while minimizing potential artifacts or blurring. Various techniques, such as advanced reconstruction algorithms and post-processing methods, are employed to improve resolution without compromising patient safety. Additionally, advancements in imaging technology, such as higher field strength in MRI or multi-detector arrays in CT, contribute to improved spatial resolution. Understanding the concept of image resolution enables radiologists to assess image quality, make informed diagnostic decisions, and effectively communicate findings to other healthcare professionals."

This example presents a single question focused on image resolution in radiology, with answers that progress from a lack of understanding at the prestructural level to a comprehensive understanding at the extended abstract level, aligning with the different levels of the SOLO taxonomy.

IV. CURRENT LITERATURE ON THE TOPIC- PROS AND CONS

Pros of SOLO Taxonomy in Medical Education

1. Applicability to diverse subjects and assignment lengths
2. Comprehensive framework for categorizing learning outcomes
3. Cross-validation with other taxonomies enhances assessment accuracy
4. Specific categorization of evaluative abilities
5. Clear hierarchical structure for understanding learning outcomes
6. Focus on depth of understanding, promoting higher-order thinking skills
7. Alignment with teaching and learning practices
8. Assessment of cognitive complexity
9. Potential for self-assessment
10. Clarity in learning progression
11. Differentiation of learning outcomes
12. Focus on metacognition
13. Transfer of learning to real-world contexts
14. Alignment with constructivist approaches
15. Assessment of depth of understanding in medical education
16. Alignment with clinical reasoning
17. Promotion of reflective learning
18. Application in clinical scenarios
19. Clear progression and feedback
20. Reliability in assessment

Pros of SOLO Taxonomy in Medical Education

- **Applicability:** SOLO taxonomy is suitable for measuring different kinds of learning outcomes across various subjects, levels of study, and assignment lengths. It is demonstrated that SOLO taxonomy can be applied to both practice-oriented and conceptual-oriented studies⁽¹⁾.
- **Comprehensiveness:** SOLO is considered comprehensive in its application, as it provides a hierarchical model that can classify students' responses based on increasing levels of structural complexity. It offers a clear framework for categorizing learning outcomes and assessing cognitive attainment⁽¹⁾.
- **Cross-validation:** The study showed that using multiple educational taxonomies, including SOLO, Bloom's taxonomy, and the reflective thinking model, can enhance the reliability and accuracy of assessing students' learning outcomes. Cross-validation with different taxonomies can provide a more comprehensive picture of students' cognitive abilities⁽¹⁾.
- **Clear Division of Categories:** The study highlighted that the reflective thinking model performed well in measuring students' critical thinking levels. It offers a specific categorization of evaluative abilities, enabling instructors and students to identify and improve critical thinking skills⁽¹⁾.
- **Clear Hierarchical Structure:** The SOLO taxonomy provides a clear and hierarchical structure for understanding and assessing the levels of student learning outcomes⁽⁴⁾. It helps educators differentiate between surface-level and deep-level understanding, allowing for more precise assessment and instructional planning.
- **Focus on Depth of Understanding:** Unlike some other taxonomies, the SOLO taxonomy specifically focuses on the depth of understanding rather than just knowledge recall⁽⁵⁾. It encourages educators to promote higher-order thinking skills and the application of knowledge in meaningful ways.
- **Alignment with Teaching and Learning:** The SOLO taxonomy closely aligns with how teachers teach and how students learn. It recognizes that both teachers and students progress from surface-level understanding to deeper constructs. This alignment makes it easier for educators to design instruction that supports students' cognitive development.
- **Assessing Cognitive Complexity:** The SOLO taxonomy provides a framework for assessing the cognitive complexity of student learning outcomes. It allows educators to design assessment tasks that align with specific levels of understanding, providing a more accurate representation of students' learning progression.
- **Potential for Self-Assessment:** The SOLO taxonomy can be taught to students, empowering them to assess their own learning outcomes. Students can learn to write progressively more difficult answers or prompts by understanding and applying the

levels of the SOLO taxonomy. This promotes student ownership of learning and self-reflection ⁽⁵⁾.

- **Clarity in Learning Progression:** The SOLO taxonomy provides a clear learning progression from lower levels of understanding to higher levels. This clarity allows educators to scaffold instruction and provide targeted support to help students advance in their learning journey.
- **Differentiation of Learning Outcomes:** The taxonomy allows for the differentiation of learning outcomes based on the depth of understanding. It helps educators tailor their instruction and assessment to meet the diverse needs of students, promoting personalized learning experiences.
- **Focus on Metacognition:** The SOLO taxonomy encourages metacognitive reflection and self-regulation by students ⁽⁵⁾. It prompts them to think about their thinking and reflect on their learning process, fostering the development of metacognitive skills that are crucial for lifelong learning.
- **Transfer of Learning:** The taxonomy emphasizes the ability to transfer knowledge and apply it in new and unfamiliar contexts. It encourages students to make connections between different concepts and transfer their learning to solve real-world problems, promoting deeper and more meaningful learning experiences.
- **Alignment with Constructivist Approaches:** The SOLO taxonomy aligns well with constructivist educational approaches that emphasize active learning, inquiry, and the construction of knowledge. It supports student-centered instruction and encourages students to engage in authentic, meaningful tasks.
- **Assessment of Depth of Understanding:** The SOLO taxonomy focuses on assessing the depth of understanding and cognitive complexity in learning outcomes. In medical education, this is crucial as it allows educators to evaluate the students' ability to apply knowledge in clinical contexts, think critically, and solve complex problems.
- **Alignment with Clinical Reasoning:** The SOLO taxonomy aligns well with the development of clinical reasoning skills, which are essential in medical practice ⁽⁵⁾. It enables educators to assess learners' progression in clinical reasoning and their ability to integrate knowledge from multiple sources to make informed decisions.
- **Reflective Learning:** The SOLO taxonomy promotes metacognition and reflective learning. It challenges medical students to examine their own thinking, consider how they are learning, and gauge the quality of their comprehension ⁽⁵⁾. The abilities necessary for lifelong learning are developed through self-evaluation and self-reflection.
- **Differentiation of Learning Outcomes:** The taxonomy allows for the differentiation of learning outcomes based on the complexity of understanding. It helps educators tailor their teaching and assessment approaches to meet the diverse needs of medical students, promoting personalized and targeted instruction.

- **Application in Clinical Scenarios:** The SOLO taxonomy is well-suited for assessing clinical knowledge and skills. It enables the design of assessment tasks that simulate real-life clinical scenarios, requiring students to demonstrate their ability to apply knowledge, make decisions, and manage patient cases effectively ⁽⁵⁾.
- **Clear Progression and Feedback:** The hierarchical structure of the SOLO taxonomy provides a clear progression of learning outcomes ⁽⁵⁾. It enables teachers to give students detailed feedback about their current comprehension level and the activities they can take to advance to the next level. This targeted feedback supports students' learning and growth.
- **Reliability in Assessment:** The SOLO taxonomy has demonstrated high inter-rater reliability, meaning that different assessors tend to agree on the levels of understanding assigned to students' work ⁽⁵⁾. This enhances the consistency and dependability of assessment outcomes.

Cons of SOLO Taxonomy in Medical education	1.	Conceptual ambiguity
	2.	Sub-levels complexity
	3.	Inter-rater reliability
	4.	Allocation of marks
	5.	Intervals between SOLO levels
	6.	Motivation and development
	7.	Variability in understanding
	8.	Limited development in certain topics
	9.	Need for explicit elaboration
	10.	Limited focus on cognitive domain
	11.	Complexity of application
	12.	Limited applicability to certain assessment formats
	13.	Simplification of learning
	14.	Limited emphasis on content knowledge

Cons of SOLO Taxonomy in Medical Education

- **Conceptual Ambiguity:** The structure of SOLO and the criteria for categorization can lead to inconsistencies and low inter-rater reliability. Some responses may be misjudged, leading to the mistaking of high cognitive attainment for low levels and vice versa. To reduce the ambiguity and to increase the assessment reliability adding sub-levels to the original SOLO scale has been suggested ⁽¹⁾.
- **Sub-levels Complexity:** While adding sub-levels to the SOLO taxonomy was suggested as a way to reduce ambiguity and increase inter-rater reliability, it also introduces complexity. The categorization process becomes more intricate, and raters may still face challenges in accurately classifying student responses ⁽¹⁾. This can cause subjectivity in scoring.
- **Inter-rater Reliability:** While the SOLO taxonomy generally has high inter-rater reliability, there can still be variations in how different educators interpret and assess student responses. Assessing responses and determining the level of understanding can be subjective, leading to differences in opinion among teachers or markers. Inter-rater reliability can be a concern when multiple markers assess student work. Teachers may have different interpretations of what constitutes a relational response or the depth of understanding at each level. This subjectivity can introduce inconsistency and affect the reliability of assessment outcomes ⁽⁶⁾.
- **Allocation of Marks:** The SOLO taxonomy focuses on assessing the depth of understanding and cognitive complexity, but it does not prescribe specific percentages or weights for each level of competence. This can create challenges in determining how many marks should be assigned to each level. The lack of standardized guidelines may result in inconsistencies across different assessors or institutions ⁽⁶⁾.
- **Intervals between SOLO Levels:** The SOLO taxonomy implies a hierarchical progression from one level to another. It does not, however, state whether the gaps between these levels are equal or how large of a jump is necessary to advance to the next level. This uncertainty can make it challenging to accurately identify the levels' limits and may lead to different interpretations⁽⁶⁾.
- **Motivation and Development:** Some students may not be motivated to develop their responses to the higher level of understanding, resulting in a proportion of descriptive responses remaining unchanged ⁽⁷⁾.
- **Variability in Understanding:** There may be variation among students in their understanding and application of the SOLO levels, leading to subjective interpretations of the levels of understanding and potential inconsistency in marking ⁽⁷⁾.
- **Limited Development in Certain Topics:** Certain topics, such as risk assessment and diagnostic thinking, may pose challenges for students, and their development in these areas may be less outstanding compared to other learning outcomes ⁽⁷⁾.

- **Need for Explicit Elaboration:** It may be necessary to engage in explicit discussions and elaboration with individual students to help them reach a sufficient level of understanding and encourage further development ⁽⁷⁾.
- **Limited Focus:** One potential limitation of the SOLO taxonomy is its narrow focus on the cognitive domain and depth of understanding. It does not explicitly address other domains, such as affective or psychomotor domains, which are important in holistic education.
- **Complexity of Application:** While the SOLO taxonomy provides a clear structure, its application can still be complex. Educators need a deep understanding of the taxonomy and its levels to effectively design assessment tasks and provide meaningful feedback. This complexity may require additional training and support.
- **Limited Applicability to Certain Assessment Formats:** The SOLO taxonomy is most suitable for assessment items that allow for a wide range of responses and demonstrate the depth of understanding. Some assessment formats, such as multiple-choice questions that primarily test recall, may not align well with the SOLO approach. Having EXIT exam in MCQ based summative assessment the use of SOLO Taxonomy in that context is questionable.
- **Simplification of Learning:** The hierarchical nature of the SOLO taxonomy may oversimplify the complexity of learning. It reduces learning outcomes to discrete levels, potentially overlooking the intricacies and multidimensionality of student understanding and skills.
- **Limited Emphasis on Content Knowledge:** While the SOLO taxonomy focuses on the depth of understanding, it may not explicitly address the acquisition of specific content knowledge. Educators need to ensure that content knowledge is integrated alongside the cognitive complexity emphasized by the taxonomy.

It's important to note that while the SOLO taxonomy offers valuable benefits, its limitations should also be considered when deciding on its use in educational settings. It's important to consider the pros and cons when evaluating the suitability and implementation of the SOLO taxonomy in specific educational contexts. The benefits and limitations should be weighed against the goals, priorities, and constraints of the teaching and learning environment.

SOLO Taxonomy in Systems Approach

At the Input Level

Aligning the curricula with assessments for verifying program objectives: The SOLO taxonomy can be used to align curricula and assessments by ensuring that the intended learning outcomes and program objectives are clearly defined and mapped to appropriate levels of understanding within the taxonomy. This alignment helps in designing assessments that accurately measure the desired levels of cognitive complexity.

Sensitizing teachers from lesson planning to assessments: The SOLO taxonomy can guide teachers in designing lesson plans and assessments that progressively scaffold students' learning. It helps teachers understand the cognitive demands of different levels and assists them in creating activities, resources, and assessments that promote deep understanding and critical thinking.

Inclusion in orientation programs: Introducing the SOLO taxonomy in orientation programs can provide teachers and educators with a common framework for understanding and evaluating learning outcomes. It helps them develop a shared language and understanding of the levels of understanding and cognitive complexity, enabling more effective collaboration and instructional planning.

Study materials based on the SOLO taxonomy: Study materials can be designed and organized based on the levels of the SOLO taxonomy. This helps students engage with learning resources that match their current level of understanding, allowing them to progress through the taxonomy levels and deepen their knowledge gradually.

At the Process Level

Asynchronous: Students' reflection on what they are learning: The SOLO taxonomy encourages metacognitive reflection and self-assessment. Students can use the taxonomy to reflect on their own learning, identify their current level of understanding, and set goals for progression. They can engage in self-reflection activities, such as journaling or self-assessment exercises, to monitor their learning journey.

Synchronous: Assessments conducted for the students: The SOLO taxonomy can guide the design and implementation of assessments conducted for students. By aligning assessments with the taxonomy levels, educators can create assessments that effectively measure students' depth of understanding and their ability to apply knowledge in different contexts. This promotes higher-order thinking and provides valuable feedback on students' progress.

At the Output Level

Students self-assessing the knowledge gained: The SOLO taxonomy empowers students to self-assess their knowledge and understanding. Students can use the taxonomy as a guide to evaluate their own learning outcomes and assess the depth of their understanding. This self-assessment process helps students become more self-aware, identify areas of strength and weakness, and set goals for further improvement.

At the Feedback Level

Feedback from the students: The SOLO taxonomy can facilitate meaningful feedback from students. Students can use the taxonomy to articulate their understanding and provide self-reflection on their learning progress. This feedback can help teachers gain insights into individual student needs and adapt their instructional strategies accordingly.

Feedback from the teachers: The SOLO taxonomy enables teachers to provide targeted and constructive feedback to students based on the levels of understanding. Teachers can use the

taxonomy to provide specific feedback that guides students' progression through the levels and promotes deeper learning. This feedback supports students' growth and helps them bridge gaps in their understanding.

By incorporating the SOLO taxonomy in these different levels and feedback processes, educators can enhance curriculum alignment, instructional planning, student self-assessment, and effective feedback practices, ultimately fostering deeper learning and understanding among students.

V. RESULTS OF PREVIOUS STUDIES ABROAD

A qualitative study done to observe the clinical reasoning pattern of undergraduate Indonesian dental students showed that the learners with inadequate knowledge relied on guessing, whereas those with adequate knowledge applied a more sophisticated reasoning pattern when solving problems ⁽⁸⁾. Here they used the SOLO taxonomy for assessing knowledge acquisition using concept maps generated ⁽⁸⁾.

The study conducted by Chrismawaty et al. aimed to observe the clinical reasoning patterns of undergraduate dental students when solving oral health problems from hypothetical cases and determine their accordance with knowledge acquisition. The study utilized verbal protocol analysis with the think-aloud method and concept mapping to gather data on the participants' clinical reasoning and knowledge structure.

The findings of the study revealed different clinical reasoning patterns among the participants, including guessing, hypothetical-deductive reasoning, elaborated hypothetical-deductive reasoning, scheme-inductive reasoning, and pattern recognition. These patterns were found to correspond to the participants' level and structure of knowledge acquisition ⁽⁸⁾.

The participants' level of knowledge structure was assessed using the Structure of Learning Outcomes (SOLO) taxonomy, which categorizes knowledge levels as pre-structural, unistructural, multistructural, relational, and extended abstract. The concept maps created by the participants were analysed and categorized based on the SOLO taxonomy levels. The study identified strengths and weaknesses in the participants' clinical reasoning and knowledge acquisition. The weaknesses included gaps in knowledge and discrepancies between the participants' clinical reasoning patterns and their level of expertise. The study also highlighted the need for improvements in dental education to enhance clinical reasoning skills and knowledge acquisition. In conclusion, the study demonstrated that undergraduate dental students employ various problem-solving strategies based on their level and structure of knowledge acquisition. The study provided recommendations for dental institutions to emphasize clinical reasoning in dental education and improve curriculum, teaching methods, and the learning environment to enhance the provision of dental health services⁽⁸⁾.

A study done at Hong Kong by Chan et al. explored the application of different educational taxonomies, including the Structure of the Observed Learning Outcomes (SOLO) taxonomy, Bloom's taxonomy, and the reflective thinking model, in measuring students' cognitive learning outcomes. The objectives were to compare these taxonomies and test their application value. The study involved a literature review to establish a conceptual framework and experimental analysis of student essays and short responses using the modified versions

of the taxonomies. The findings of the study indicated that SOLO taxonomy is suitable for measuring different kinds of learning outcomes across various subjects, levels of study, and assignment lengths. It demonstrated that SOLO taxonomy can be applied to practice-oriented and conceptual-oriented studies. The study also found that adding sub-levels to the SOLO taxonomy can reduce ambiguity and increase inter-rater reliability. Cross-validation with different taxonomies, including Bloom's taxonomy and the reflective thinking model, can enhance the accuracy of assessing students' learning outcomes ⁽¹⁾.

However, the study highlighted the limitation of SOLO in terms of its conceptual ambiguity, which can lead to inconsistencies and low inter-rater reliability. It suggested that further research should focus on addressing this issue by exploring ways to improve agreement among raters. Additionally, the study indicated that the reflective thinking model performed well in assessing students' critical thinking levels, providing a specific categorization of evaluative abilities. Overall, the study recommended the use of the reflective thinking model for assessing critical and evaluative thinking abilities and acknowledged the advantages and applicability of the SOLO taxonomy while acknowledging the need for further research and comparison with other taxonomies ⁽¹⁾.

In a study conducted in Edinburgh, the Undergraduate Medical Programme was reconstructed by using SOLO taxonomy and constructively aligning course assignments and examination for creating deep approach learning in first and second

year students revealed that they had high scores for deep and strategic approaches to learning and studying while lower scores for a surface approach, but there was only little significant change in the scores occurred during the whole of the medical degree programme apart from some tendency for the surface approach to lessen⁽⁵⁾.

The study by Reid et al. aimed to investigate whether the redesigned curriculum of a medical degree program promoted a deep approach to learning and studying and deterred a surface approach among medical students. The study used the Approaches and Study Skills Inventory for Students (ASSIST) to measure the students' approaches to learning. The results showed that at the beginning of the program, students already had relatively high scores for deep and strategic approaches to learning and lower scores for a surface approach. Over the course of the program, there was a slight trend towards an increase in deep and strategic approaches and a decrease in the surface approach, although these changes were not statistically significant in all cohorts. The study suggested that the curriculum and learning environment had some influence on the students' approaches to learning, but the extent of that influence was uncertain. The curriculum included problem-based learning and learner-centered approaches, but the results did not show a significant increase in deep learning scores, indicating that the changes in the learning environment may not have been strong enough to alter the students' established approaches. The study also noted that students' approaches to learning may have been established prior to university entry, and that the time allocated to activities promoting deep learning may not have been sufficient to overcome the students' preference for surface learning. Additionally, the students' perceptions of the learning environment and their own cognitive and metacognitive strategies played a role in their study strategies. In conclusion, the study found that while some changes in students' approaches to learning occurred over the course of the medical degree program, the overall changes were relatively small and the deep learning scores did not significantly increase. Further research is

needed to explore the influence of different curriculum styles on students' approaches to learning ⁽⁵⁾.

In a study by Svensäter et al, conducted at Malmö University, Sweden, assessment model blending formative and summative assessment based on SOLO taxonomy presented a real interdependence between the assessments and provided information that meets the needs of students as learners, education institutes and health care organisations. They also concluded that the SOLO taxonomy can be used to emphasise the importance of developing and assessing cognitive complexity.⁽⁷⁾

The study by Svensäter et al discusses an assessment model that blends formative and summative assessments using the SOLO taxonomy in the context of health care education. The study was conducted with last-year students in three consecutive cohorts. The assessment model consisted of formative assessments at the end of Course I and summative assessments at the end of Course II. In the formative assessment, students' responses to real-life scenarios were assessed using the SOLO taxonomy, with three levels of understanding: incorrect, descriptive, and relational. Individual feedback was provided to students for each response, aiming to support their development of understanding. The summative assessment in Course II evaluated students' new responses and made a final judgement of their performance. The results showed that the assessment model successfully evaluated the development of students' understanding over time. A significant number of responses progressed to higher levels of understanding from the formative to the summative assessment. The model provided information unique to each student, allowing for individualized assessment and feedback. The assessment model demonstrated the interdependence between formative and summative assessments. It effectively combined developmental assessment with judgemental assessment, providing comprehensive information for students, educational institutes, and healthcare organizations. The use of the SOLO taxonomy facilitated the assessment of students' levels of understanding and cognitive skills integration. The study also identified areas for improvement in the courses. Some topics, such as risk assessment and diagnostic thinking, showed less development in students' understanding. Students' feedback and evaluation provided insights into their perception of the assessments and the relevance of the levels of understanding. Overall, the article highlights the value of blending formative and summative assessments using the SOLO taxonomy. The assessment model supports students' developmental progress, allows for judgement of their performance, and provides valuable information for quality enhancement in healthcare education ⁽⁷⁾.

In a study by Zipp et al, conducted at Seton Hall University, New Jersey & Kessler Institute of Rehabilitation Residency in Neurologic Physical Therapy used SOLO taxonomy as a framework for developing learning experiences to develop critical reflection skills in both the neurologic resident and entry level physiotherapy students. They had used it to design learning environments that capitalized the strengths of both and to create insightful educational experiences for students during their didactic training ⁽⁹⁾.

In a study by Ilguý et al, conducted at Yeditepe University, Turkey compared Case based and lecture based learning in Dental education using SOLO Taxonomy. Their study concluded that the students who were taught with CBL had higher scores at the top two levels of the SOLO taxonomy than students taught with LBL ⁽¹⁰⁾.

In a study by Prakash et al, conducted by the AIMST University, Kedah, Malaysia student perceptions regarding the usefulness of the SOLO taxonomy was evaluated by comparing two groups one with explicit illustration of SOLO taxonomy combined with advice on better answering descriptive questions and the other with providing advice for better answering test questions but without any reference to SOLO taxonomy. Although the scores in both the groups were comparable, the majority of the participants indicated that the knowledge of the SOLO Taxonomy would help them study and prepare better answers for questions of the descriptive type ⁽⁶⁾.

The practical issue were the SOLO taxonomy does not specify what percentage of marks to be awarded for a particular level of competence and whether the intervals between different SOLO levels are equal and the other for students for teachers marking responses there would be difference in opinion of what is what constitutes relational response and what constitutes understanding. This underscores the importance of repeated illustrations and discussions with students and between faculty members as to what would be viewed as declarative knowledge and what would be considered a sufficiently relational response at each level of the program ⁽⁶⁾.

VI. IMPLEMENTATION IN THE INDIAN SITUATION

Sinha et al performed a study at AIIMS, Deoghar, using the SOLO taxonomy to ascertain the capability of ChatGPT in solving higher order reasoning in the subject of pathology. The study involved using SOLO taxonomy to score the responses and 86% of the responses were in the relational category in SOLO Taxonomy. They have concluded that the text outputs created a meaningful response. They had suggested that the academicians and the students can also use such program to solve reasoning type questions ⁽¹¹⁾.

Scope of Using SOLO Taxonomy in CBME

The Structure of the Observed Learning Outcome (SOLO) taxonomy can be utilized in competency-based medical education (CBME) in India. The SOLO taxonomy is a framework for evaluating the quality and depth of individual learning outcomes. It categorizes learners' responses into different levels of understanding, ranging from simple recall to complex and abstract thinking.

In CBME, the focus is on the attainment of specific competencies, which include not only knowledge but also skills, attitudes, and behaviours. The SOLO taxonomy can be employed as an assessment tool within CBME programs to assess learners' progression and attainment of these competencies.

By using the SOLO taxonomy, educators can design assessment tasks and rubrics that align with the defined competencies. The taxonomy provides a systematic way to categorize learners' responses based on the depth of their understanding and their ability to apply knowledge in context. It helps identify whether learners are achieving the desired outcomes at the appropriate levels of competency.

Implementing the SOLO taxonomy in CBME allows educators to:

- **Define Competency Levels:** The taxonomy provides a clear framework for defining different levels of competency. It helps educators articulate the expected levels of understanding and performance for each competency, making it easier to communicate expectations to learners.
- **Design Assessments:** Educators can design assessment tasks that align with the defined competencies and incorporate the different levels of the SOLO taxonomy. This ensures that assessments measure the desired outcomes and provide meaningful feedback to learners.
- **Track Learner Progression:** The SOLO taxonomy allows educators to track learners' progression from lower to higher levels of competency. It provides a roadmap for monitoring learners' growth and identifying areas where additional support or instruction may be needed.
- **Guide Instruction:** The taxonomy can guide instructional strategies by helping educators design learning experiences that target specific competency levels. It provides a framework for scaffolding learners' progression and promoting deeper understanding.

However, it is important to note that the SOLO taxonomy is just one tool among several that can be used in CBME. It should be integrated with other assessment methods and strategies to provide a comprehensive evaluation of learners' competencies. Additionally, the specific competencies and assessment criteria may vary across different medical institutions and specialties, so customization and adaptation of the SOLO taxonomy to local contexts may be necessary.

VII. AI IN USING SOLO TAXONOMY IN MEDICAL EDUCATION

In the study by Sinha et al, that explored the capability of ChatGPT, an AI-based conversational program, in solving higher-order reasoning questions in the field of pathology. The study aimed to assess the accuracy and reliability of ChatGPT in providing meaningful responses to complex queries. The researchers conducted a cross-sectional study using the current version of ChatGPT. They randomly selected 100 higher-order reasoning questions from their institution's question bank, covering various systems in pathology. The responses generated by ChatGPT were collected and evaluated by three expert pathologists using a scoring system and the Structure of the Observed Learning Outcome (SOLO) taxonomy. The results showed that ChatGPT was able to solve the higher-order reasoning questions with a relational level of accuracy. The program provided meaningful responses within an average time of 45.31 seconds per answer. The majority of the responses fell into the "relational" category in the SOLO taxonomy. The study found no significant difference in the scores of responses across different organ systems in pathology, indicating that ChatGPT's performance was consistent across various topics. The evaluation by the three pathologists showed an excellent level of interrater reliability ⁽¹¹⁾.

The authors concluded that ChatGPT can be a valuable tool for assisting students and academicians in solving reasoning-type questions in pathology. The program's relational level of accuracy and its ability to provide meaningful responses make it a useful resource. However, further studies are needed to evaluate the program's accuracy in future versions. The study highlights the potential of AI, specifically ChatGPT, in healthcare education. While AI systems have limitations and cannot replace human expertise, their ability to process and analyse vast amounts of data can support decision-making and problem-solving tasks. Careful use of AI technology, along with continuous monitoring and updating, can enhance its application in education and healthcare systems ⁽¹¹⁾.

AI like ChatGPT can be useful in utilizing the SOLO (Structure of Observed Learning Outcome) taxonomy in medical education in several ways if developed accordingly:

Personalized Learning: AI can provide personalized learning experiences by adapting the level of complexity in the questions and prompts based on the learner's proficiency level. It can assess the learner's understanding and knowledge and generate appropriate questions aligned with each level of the SOLO taxonomy, allowing for tailored instruction and targeted learning experiences.

Automated Assessment: AI can assist in automating the assessment process by analyzing and evaluating student responses based on the SOLO taxonomy levels. By understanding the structure and complexity of the responses, AI models can provide immediate feedback, identify areas of improvement, and even assign appropriate learning materials or resources to help students progress to higher levels of understanding.

Adaptive Feedback: AI can provide adaptive feedback based on the SOLO taxonomy, offering insights into the student's thinking and guiding them towards deeper levels of understanding. The model can analyze the student's responses, identify misconceptions, and provide targeted feedback that promotes critical thinking and encourages students to reflect on their learning process.

Learning Analytics: AI-powered systems can collect and analyze large amounts of data generated from student interactions and assessments. This data can be used to gain insights into student progress, identify common misconceptions, and inform instructional decisions. Educators can utilize these analytics to understand how students are progressing through the different levels of the SOLO taxonomy and make data-driven interventions to enhance learning outcomes.

Curriculum Design: AI can assist in the design of curriculum and instructional materials by aligning them with the levels of the SOLO taxonomy. AI models can generate appropriate learning objectives, activities, and assessments for each level, ensuring a coherent and scaffolded learning experience. This can help educators in creating well-structured and targeted educational resources that facilitate the development of higher-order thinking skills.

It's important to note that while AI can be a valuable tool in utilizing the SOLO taxonomy, it should complement and support the expertise and guidance of educators. The human element is crucial in interpreting and contextualizing the results generated by AI systems and providing meaningful guidance to students throughout their learning journey.

VIII. COMPARISON OF SOLO TAXONOMY WITH OTHER TAXONOMIES

Bloom's taxonomy is commended for its comprehensive focus on various taxonomic domains and levels. It allows educators to plan outcomes-based education by ensuring alignment between intended outcomes, instruction, and assessment. The taxonomy encompasses cognitive, affective, and psychomotor domains, providing a broad framework for educational planning.

In contrast, the SOLO taxonomy takes a different approach by primarily focusing on the classification of knowledge from its most superficial level to its deepest level. This taxonomy is particularly relevant in health professions curricula, where the aim is to foster deep learning that promotes critical and creative thinking. The SOLO taxonomy enables structured observation of learning outcomes, allowing educators to evaluate the depth of knowledge demonstrated by learners. It is especially useful when evaluating test items that require open-ended or supply-type answers, as they provide opportunities for students to demonstrate their understanding and application of knowledge.

However, it's important to note that the SOLO taxonomy has limitations. One limitation is that it primarily focuses on the depth of knowledge and does not encompass the other domains included in taxonomies such as Bloom's taxonomy, Fink's taxonomy, or Miller's pyramid of clinical competence. These taxonomies encompass additional dimensions beyond knowledge, including skills, attitudes, and clinical competence. Therefore, while the SOLO taxonomy is valuable for assessing the depth of knowledge, educators should also consider incorporating other taxonomies or frameworks to assess and develop a comprehensive range of learning outcomes.

By understanding the strengths and limitations of various taxonomies, educators can make informed decisions on which taxonomy or combination of taxonomies best align with their educational goals and enable a comprehensive assessment and development of student learning outcomes.

Table 1: Comparison between SOLO Taxonomy with Bloom's Taxonomy

	SOLO Taxonomy	Bloom's Taxonomy
Development	Research-based structure of student learning outcomes	Developed from a committee proposal by educators
Theory	Theory about teaching and learning	Theory about knowledge
Cognitive Complexity	Based on ascending levels of cognitive complexity	Questionable hierarchical link between levels
Inter-rater Reliability	High inter-rater reliability	Low inter-rater reliability

Communication	Can be communicated through text, hand signs, and symbols	Can be communicated through text alone
Task and Outcome	Allows task and outcome to be at different levels	Not designed to level outcomes against each task
	SOLO Taxonomy	Bloom's Taxonomy
Cognitive vs Difficulty	Distinguishes between cognitive complexity and task difficulty	Does not explicitly address this distinction
Clarity of Verbs	Clarity of verb use for each level	Verb use can be confusing across levels
Declarative and Functioning Knowledge	Can be used to examine levels of declarative and functioning knowledge, including metacognitive reflection	Primarily focuses on cognitive skills
Simplicity	Simple and can be used by young students to assess learning outcomes	Provides a clear progress and next step for every learner

Advantages of the SOLO model over Bloom's taxonomy in the evaluation of student learning:

Item Construction and Scoring: The SOLO model offers advantages in item construction and scoring. It provides a clear framework for designing assessment items that align with the levels of cognitive complexity. This helps ensure that assessments accurately reflect students' understanding and progress. Additionally, the SOLO taxonomy can be used to score the items, allowing for a systematic and reliable evaluation of student responses.

Focus on Student Learning: The SOLO taxonomy incorporates features that consider how students learn and how teachers can devise instructional procedures to support their development of progressively more complex cognitive processes. It emphasizes the growth in students' understanding and their ability to engage in higher-order thinking. This focus on the learning process allows teachers to align their instructional practices with the stages of student learning.

Teachability to Students: Unlike Bloom's taxonomy, which is often used more by teachers than by students, the SOLO taxonomy can be taught to students. Students can learn to write progressively more difficult answers or prompts by understanding and applying the levels of the SOLO taxonomy. This empowers students to take an active role in their own learning and provides them with a clear framework for self-assessment and self-improvement.

Parallel to Teaching and Learning: The SOLO taxonomy closely parallels how teachers teach and how students learn. Both teachers and students tend to progress from more surface-level understanding to deeper constructs. The four levels of the SOLO taxonomy mirror this progression, making it easier for teachers to design instruction that supports students' cognitive development.

Flexibility and Proficiency: The SOLO levels can be interpreted relative to the proficiency of the students. Even young students can be taught to derive general principles and suggest hypotheses, albeit at a different level of abstraction and detail compared to older students. This flexibility allows for the construction of assessment items that assess students' understanding at an appropriate level for their age and ability.

Ease of Identification and Categorization: Compared to some experiences with Bloom's taxonomy, the identification and categorization of the SOLO levels are relatively easy. The clear structure and hierarchical progression of the SOLO taxonomy make it easier for teachers to recognize and classify student learning outcomes.

"Plus One" Principle: The SOLO taxonomy encourages teachers to use the "plus one" principle when selecting appropriate learning materials for students. This principle involves aiming to move students one level higher in the taxonomy through the careful selection of learning resources and instructional sequencing. It promotes a gradual and systematic progression in students' cognitive development.

These advantages highlight the strengths of the SOLO model in evaluating student learning. By considering how students learn and providing a clear framework for item construction, scoring, and instructional planning, and the SOLO taxonomy supports effective assessment practices and promotes student engagement and growth in cognitive complexity.

Table 2: Comparison between SOLO Taxonomy, Bloom's Taxonomy, Webb's DOK Framework, Fink's Taxonomy and Miller's Pyramid of Clinical Competence

Taxonomy/ Framework	SOLO Taxonomy	Bloom's Taxonomy	Webb's DOK Framework	Fink's Taxonomy	Miller's Pyramid of Clinical Competence
Scope of Application	Cognitive domain across subject areas	Multiple domains of learning	Primarily cognitive domain	Higher education across disciplines	Medical education, clinical skills
Cognitive Complexity	Emphasizes depth of understanding and cognitive complexity	Hierarchy of cognitive skills, from lower to higher order	Ranges from recall to extended application and synthesis	Covers different levels of learning outcomes	Progression of clinical skills from knowledge to application

Assessment and Instructional Design	Useful for learning objectives, assessments, and strategies	Guides assessments and instructional strategies	Helps in designing assessments and instruction	Supports course design and holistic learning outcomes	Assesses and develops clinical competence
Domain Coverage	Primarily cognitive domain	Cognitive, affective, psychomotor	Primarily cognitive domain	Cognitive, affective, learning how to learn	Primarily psychomotor, cognitive
Taxonomy/ Framework	SOLO Taxonomy	Bloom's Taxonomy	Webb's DOK Framework	Fink's Taxonomy	Miller's Pyramid of Clinical Competence
Levels/ Dimensions	Five Hierarchical levels of structural complexity	Six hierarchical levels of cognitive processes	Four levels of cognitive demand	Six categories of learning objectives	Five levels of clinical competence
Application	Measuring learning outcomes across subjects and levels	Designing learning objectives, assessments, and instruction	Aligning instructional materials and assessments	Guiding instructional design and transformative learning	Assessing and evaluating clinical competence
Educational Emphasis	Depth of understanding and cognitive attainment	Promoting higher-order thinking and application of knowledge	Depth of understanding, reasoning, and problem-solving	Integration of knowledge, skills, and personal competencies	Acquisition of clinical skills, knowledge, and behaviors

IX. CONCLUSION

The SOLO taxonomy offers a valuable framework for assessing learning outcomes in medical education. Its applicability across various subjects, assignment lengths, and levels of study makes it a versatile tool for educators. The taxonomy's comprehensive nature, with its hierarchical model of categorizing learning outcomes based on increasing levels of structural complexity, provides clarity and precision in assessing cognitive attainment.

One of the significant advantages of the SOLO taxonomy is its alignment with teaching and learning practices. It recognizes the progression from surface-level understanding to deeper

constructs, allowing educators to design instruction that supports students' cognitive development. The focus on depth of understanding, higher-order thinking skills, and the application of knowledge in meaningful ways promotes a more robust and holistic approach to medical education.

Moreover, the SOLO taxonomy has demonstrated cross-validation potential when used in conjunction with other educational taxonomies. This enhances the reliability and accuracy of assessing students' learning outcomes by providing a more comprehensive picture of their cognitive abilities. Additionally, the taxonomy's clear division of categories, particularly in evaluating critical thinking levels, allows both instructors and students to identify and improve critical thinking skills effectively.

The SOLO taxonomy also offers the opportunity for self-assessment, empowering students to assess their own learning outcomes. By understanding and applying the taxonomy's levels, students can progressively develop more complex answers and prompts, fostering student ownership of learning and facilitating metacognitive reflection.

While the SOLO taxonomy has numerous strengths, it is important to acknowledge its potential limitations. Its generalizability and sensitivity to specific learning environments and contexts may vary. Additionally, the successful implementation of the taxonomy may require ongoing support, professional development, and alignment with the overall curriculum design.

In conclusion, the SOLO taxonomy provides a valuable framework for assessing learning outcomes in medical education. Its focus on depth of understanding, alignment with teaching and learning practices, and potential for self-assessment make it a valuable tool for educators. By incorporating the SOLO taxonomy into medical education, educators can promote higher levels of cognitive engagement, critical thinking, and the application of knowledge, ultimately fostering the development of competent and reflective medical practitioners.

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