Mapping the Knowledge Structure of Students with Intellectual Disabilities Through SOLO Taxonomy-Based Automated Assessment

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Abstract: *Background*: Mapping students with intellectual disabilities' (ID) knowledge structures is a critical challenge in inclusive education. Traditional assessments often fail to capture the nuanced cognitive development of this population. This limits teachers' ability to design differentiated interventions. This study aimed to develop and test a SOLO Taxonomy-based Automated Assessment (SOLO-AA) system tailored for students with mild to moderate intellectual disabilities. It also examines its effectiveness in mapping hierarchical knowledge structures.

Method: An exploratory sequential mixed-methods design was used. In the qualitative phase, in-depth interviews with six special education teachers and analysis of lesson plans revealed linguistic limitations, fragmented knowledge, and a reliance on visual and contextual learning. These findings informed the design of a visual-interactive assessment system. In the quantitative phase, SOLO-AA was piloted with 30 students aged 11-15 years. Content validity was evaluated using Aiken's V. Reliability was assessed with KR-20 and Rasch modeling.

Result: Content validity reached a score of 0.89 (highly valid), and KR-20 reliability was 0.82 (highly reliable). Most students were at the unistructural (36%) and multi-structural (30%) levels. Fewer reached the relational level (15%), and only 3% reached the extended abstract level. Rasch analysis showed person reliability of 0.79 and item reliability of 0.91. This indicates instrument stability and appropriate item difficulty for this population. Visual-based items were significantly easier. Tasks requiring concept integration were more challenging.

Conclusion: SOLO-AA provides a fine-grained mapping of students' knowledge structures, moving beyond binary judgments. It helps teachers design differentiated instruction, improves diagnostic precision, and offers a scalable AI-assisted solution for inclusive education. This study links SOLO-AA with adaptive automated assessments and shows its utility in special education. Future research should include diverse ID populations, employ longitudinal designs, and integrate culturally relevant content to deepen contextual meaning.

Keywords: Automated assessment, inclusive education, intellectual disabilities, mixed-methods, SOLO taxonomy.

INTRODUCTION

Understanding how students with intellectual disabilities (ID) build knowledge is a crucial challenge in inclusive education. Traditional methods often fail to capture their cognitive development. These assessments rely on quantitative systems that overlook the structure of student thinking [1-4]. They emphasize correct answers without considering deeper conceptual understanding. As a result, teachers struggle to design tailored interventions [5, 6].

In this study, ID means individuals with significant limitations in intellectual functioning and adaptive behavior. These limitations appear before age 18, in accordance with DSM-5 and AAIDD guidelines. To align with clinical and educational terminology, we focus on students with mild intellectual disabilities. These students struggle with abstract reasoning, working memory, and concept integration, but can participate in structured academic learning with the right support.

In response to these limitations, there has been increasing interest in using context, particularly for students with ID (Intellectual Disabilities), an area that remains underexplored. Existing studies primarily apply SOLO-AA in general education or higher education settings [7, 8]. Students can explicitly express their reasoning, which is essential for understanding their thought processes and knowledge structures. This creates a critical gap, specifically in how the SOLO-AA taxonomy can be adapted and automated to assess students with intellectual disabilities' knowledge structures.

To understand students with intellectual disabilities, we must look at their academic performance and how they organize and process information. Many rely on visual and concrete representations. These reduce

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cognitive load and support understanding [9, 10]. Their knowledge often develops in fragments; they can recall facts but struggle to see relationships between concepts. This underscores the need for hierarchical frameworks like SOLO-AA. Such tools help educators recognize levels of understanding, from basic concept recognition to relational and abstract thinking. By using these ideas, this study explores how automated SOLO-AA can more clearly reveal cognitive development patterns in students with intellectual disabilities.

To address these issues, this study introduces SOLO-AA for students with mild to moderate intellectual disabilities. The study is novel because: (1) it uses an adaptive algorithm to detect response patterns and map them to SOLO levels, and (2) it applies AI-based analytics to automate cognitive restructuring diagnostics in real-time. Unlike conventional assessments, this system offers a structure-based, qualitative view of learning progress-a rarely used strategy in inclusive settings. SOLO-AA includes a simple interface for easy teacher use. The system generates scores and individual cognitive profiles, helping teachers create personalized, differentiated strategies. By visualizing students' SOLO levels after each session, teachers can monitor progress over time and identify areas that need more support.

The SOLO Taxonomy provides educators with a way to analyze the quality and depth of students' understanding rather than just evaluating right or wrong answers. It organizes learning into hierarchical levels of complexity, from pre-structural to extended abstract**.** Each level shows a deeper integration of knowledge. For students with intellectual disabilities, a hierarchical framework is useful because their cognitive development often progresses slowly and unevenly.

Traditional assessments often reduce learning to "correct" or "incorrect" responses. This overlooks key stages of conceptual development. Using SOLO-AA allows educators to see how students organize and connect ideas as they build understanding. The SOLO-AA serves as both an evaluation tool and a diagnostic aid for meaningful instructional planning in inclusive education.

This approach also supports ongoing, adaptive summative assessment. It focuses on developing models such as the SOLO Taxonomy, which classifies outcomes by cognitive complexity from pre-structural to extended abstract [11-13]. Teachers gain deeper insight into knowledge construction, not just recall. In inclusive education, this taxonomy helps create more adaptive, differentiated interventions sensitive to students' cognitive needs.

However, the SOLO-AA framework in special education requires further conceptual elaboration to deepen students' understanding. Furthermore, the development of SOLO-AA also contributes to the literature on inclusive education by offering an assessment model that is sensitive to the complex thinking of students with intellectual disabilities. This addresses a gap in previous research that tends to generalize assessment methods without considering the unique cognitive characteristics of students with intellectual disabilities. Thus, SOLO-AA is not only a technological innovation but also a pedagogical instrument that supports the creation of a more equitable, inclusive, and data-driven learning ecosystem for instructional decision-making. The problem formulation in this study is how the results of developing an automated assessment system based on the SOLO-AA can be applied and how the SOLO-AA can effectively map students with intellectual disabilities' knowledge structures. This study builds on previous research showing that the application of adaptive technology can improve the accuracy of learning assessments for students with special needs; however, most of these studies focus on functional skills or basic academics [14, 15].

Furthermore, the SOLO-AA has proven effective for mapping students' conceptual development across general and higher education [16, 17]. But there is minimal exploration in the context of intellectual disabilities [18-20]. Furthermore, studies by Shrestha & Roffey [21], Fitriyah [22], and Adeoye *et al.* [23] confirm that structure-based assessments can provide richer insights into students' thinking patterns than conventional assessments that only assess true-false answers. Based on these findings, this study seeks to bridge two critical gaps: the limitations of qualitative evaluations for students with ID and the limited implementation of automated structure-based taxonomies. It also addresses calls for more personalized and developmentally sensitive assessment tools [24] to support learning equality in inclusive classrooms.

MATERIAL AND METHOD

Method

The study employed a mixed-methods exploratory sequential design, integrating qualitative and quantitative approaches to develop and map the knowledge structures of students with intellectual disabilities (ID) [25-27]. This study adopted an exploratory sequential mixed-methods design, which combines qualitative exploration with subsequent quantitative validation. The research design followed two clearly defined stages: a qualitative, exploratory phase aimed at identifying the cognitive characteristics and learning preferences of students with intellectual disabilities through teacher interviews and lesson-plan analysis. Quantitative validation phase, aimed to test the SOLO-AA instrument through pilot implementation, validity testing, and reliability analysis.

This approach was chosen to develop an assessment instrument for students with intellectual disabilities that requires a deep understanding of their cognitive and learning characteristics before conducting statistical tests. In the first stage, qualitative data were collected through in-depth interviews with special education teachers and analysis of instructional documents. This phase aims to explore how students with intellectual disabilities process information, respond to instructions, and demonstrate conceptual understanding in classroom settings.

The insights obtained from this qualitative phase served as the foundation for designing the SOLO-AA. After the instrument's conceptual framework was established, the study proceeded to the quantitative phase, which examined its psychometric properties**.** Content validity was assessed using Aiken's V coefficient, while reliability was examined using the Kuder-Richardson Formula 20 (KR-20) to evaluate internal consistency. In addition, the Rasch measurement model was employed to simultaneously analyze item difficulty and person ability. The integration of these analytical approaches enabled the instrument to be evaluated not only for reliability but also for measurement precision and construct alignment. Pedagogically, this research offers teachers a robust visual understanding of how students' ideas developed, enabling informed instructional decision-making. Technologically, the study proposes a scalable AI-based model 2021). The overall research procedure of the exploration sequential mixed-methods design is presented in Figure **1**.

Several limitations should be acknowledged when interpreting the findings of this study. First, the quantitative phase involved a relatively small sample (n = 30), which may limit the statistical generalizability of the findings. Second, the participants consisted exclusively of students with mild intellectual disabilities, meaning that the results may not directly apply to individuals with moderate or severe intellectual disabilities who may exhibit substantially different cognitive and adaptive profiles. Third, the study was conducted in a limited number of special schools in Indonesia, which may have influenced contextual factors such as curriculum structures, teacher practices, and access to technologies. Therefore, the findings should be interpreted primarily as exploratory evidence supporting the feasibility of SOLO-AA rather than as definitive conclusions applicable to all student populations with intellectual disabilities.

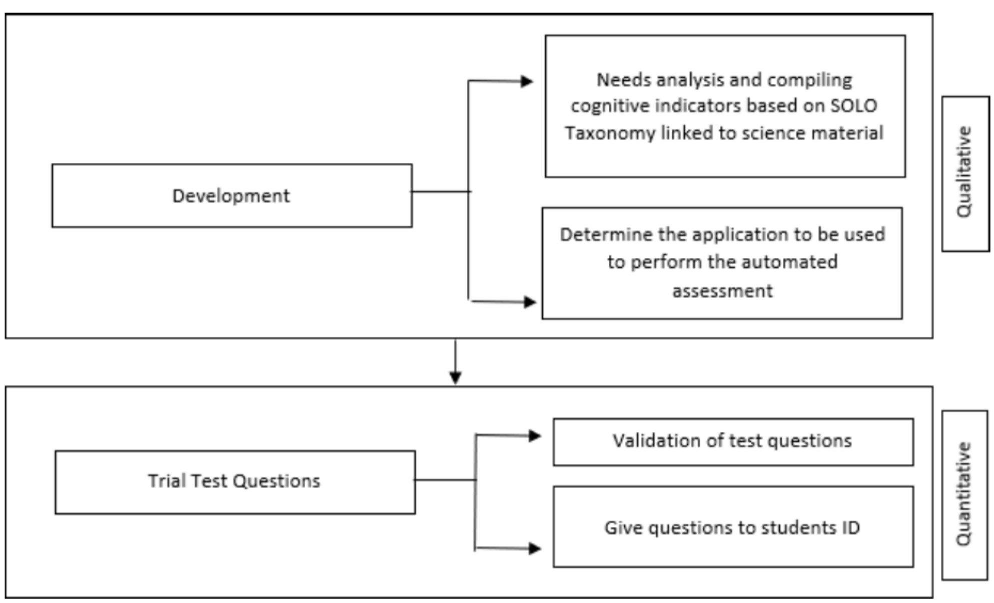

Figure 1: Research procedures of the exploration sequential mixed-methods design.

Instrument

The instruments used in this study included a science test structured based on the SOLO Taxonomy indicator matrix. The test was then entered into an automated assessment platform, a formative application integrated with an AI classification algorithm that classified student responses into SOLO levels. In addition to the test, this study also used a validation questionnaire to assess the quality of the content, media, and question construction. This is applicable across various special education contexts. This approach promises to close the assessment equity gap and advance inclusive practices through evidence-based personalization.

The assessment instrument developed in this study was structured around the Solo Taxonomy framework, which served as the conceptual basis for organising assessment items by levels of cognitive complexity. Each test item was designed to represent one of the five SOLO levels: pre-structural, uni-structural, multi-structural, relational, and extended abstract. This structure enabled the instrument to capture variations in students’ understanding rather than merely measuring task completion. To accommodate the cognitive characteristics of students with intellectual disabilities, the SOLO-AA items were adapted into visual and interactive formats, including image-based prompts, simplified instructions, and contextual representations. These adaptations ensured that the SOLO framework could be meaningfully applied within special education settings while maintaining its theoretical integrity as a hierarchical model of cognitive development.

The automated assessment component of the SOLO-AA system does not rely on a fully trained machine learning model. Instead, it operates using a rule-based classification algorithm derived from the SOLO taxonomy framework. Each test item is pre-coded according to its targeted SOLO level (pre-structural, uni-structural, multi-structural, relational, and extended abstract). Student responses are automatically processed by the system through predefined scoring rules that evaluate response accuracy, conceptual linkage, and the number of relevant elements identified in the answer. Based on these criteria, the algorithm maps each response to the corresponding SOLO level. The automated scoring process then aggregates individual item classifications to generate a hierarchical knowledge profile for each student.

The system's decision-making process is based on a structured classification system. First, student responses are recorded through the digital assessment interface. Second, the system applies to a rule-based scoring matrix aligned with SOLO taxonomy indicators, including concept recognition, multiplicity of ideas, relational linkage, and abstraction. Third, the algorithm computes the dominant SOLO level from the distribution of classified responses across test items. This process enables the system to automatically generate a cognitive profile that reflects the hierarchical structure of student understanding rather than a simple correct-incorrect score.

Automated Analytical Mechanism of the SOLO-AA System

The SOLO-AA system is equipped with an automated analysis module that assists in assessing students' answers according to the SOLO taxonomy. While the system uses computational assistance in the assessment process, its analysis mechanism does not rely on complex artificial intelligence. It primarily operates using predefined classification rules supported by automated text analysis. Initially, student answers from alternative assessment tasks are processed by identifying key terms, removing irrelevant words, and identifying conceptual elements related to the learning topic. Through this process, the system can identify several important indicators from students' answers, such as the number of relevant scientific concepts, the relationships between concepts, the depth of explanation, and the level of reasoning demonstrated by students.

These indicators are then analyzed using a set of classification rules developed based on the characteristics of each level in the SOLO taxonomy. These rules form the basis for decision-making within the system. For example, answers containing irrelevant or inappropriate concepts are categorized at the pre-structural level. If an answer demonstrates understanding of only one relevant concept, it is categorized as uni-structural. Answers containing several relevant but unconnected concepts are classified as multi-structural. If students can demonstrate clear relationships among concepts, their answers fall into the relational level. Meanwhile, responses that exhibit the capacity to generalize concepts, construct higher-order abstractions, and transfer or apply knowledge across broader and more complex contexts are systematically categorized within the extended abstract level, reflecting a sophisticated and integrative form of understanding. Through this rule-based evaluation process, the system can automatically determine the SOLO taxonomy level for each student's answer.

The results of this automatic classification are then stored and displayed in visualizations to help understand students' knowledge structures and learning progress. Although the analysis is automated, educators can still review the results to ensure alignment with learning objectives. In this study, AI-based analytics refers to the use of computational methods to analyze students' answers. However, the primary mechanism used is a rule-based decision-making system combined with automated text analysis. This approach allows the system to support large-scale assessment processes while maintaining alignment with the theoretical framework of the SOLO taxonomy.

Data Analysis

Content validity was assessed using Aiken's V with input from 5 experts (cutoff value ≥ 0.75). Inter-rater reliability was measured using Cohen's kappa. Descriptive statistics were used to explore the distribution of SOLO levels among students. Data analysis was conducted in several stages to ensure the methodological robustness of the developed instrument. First, content validity was examined using Aiken's V**,** based on expert judgments from five specialists in special education and educational assessment. This procedure was used to determine the extent to which the assessment items represented the theoretical constructions of the SOLO taxonomy and were appropriate for students with intellectual disabilities.

Second, the instrument's internal consistency reliability was calculated using the Kuder-Richardson Formula 20 (KR-20)**,** which is commonly used with dichotomous test items. This analysis was used to determine whether the items consistently measured the intended construct. Finally, the Rasch model was applied to provide a more detailed psychometric evaluation. Rasch analysis enabled the examination of both item reliability and person reliability, as well as the alignment between item difficulty and student ability levels through the item-person map. This analysis provided a clearer sense of how well the assessment items performed across various levels of students' ability.

Ethical Consideration

This study was approved by the principals of special schools at the junior high school level: Palembang, Bengkulu, and Lubuk Linggau. This study was executed in compliance with ethical standards for research involving students with special needs. Parental consent and school permission were obtained prior to data collection, and pseudonyms were used to maintain participant confidentiality. According to the National Health Research Ethics Guidelines (2017) issued by the National Commission for Health Research Ethics under the Ministry of Health of the Republic of Indonesia, formal approval from a research ethics committee was not required, as this study involved non-invasive educational activities with minimal risk. This study was conducted with institutional permission and informed consent from the students' legal guardians while ensuring confidentiality and voluntary participation.

RESULT

Qualitative Stage Findings

The initial stage of this research used an exploratory qualitative approach, involving six special education teachers at a special-needs school (SNS-C) with experience teaching students with intellectual disabilities aged 7-15 years. In-depth interviews and analysis of Lesson Plan documents were used to explore the characteristics of student knowledge. The interview results indicated that students with intellectual disabilities have linguistic and cognitive limitations, particularly in understanding long sentences or multi-step instructions.

Teacher A stated:

> "*If the instructions are too long, they will immediately get confused. They should be made into short sentences, sometimes with the help of pictures or gestures*."

This finding was reinforced by Teacher C:

> "*Students' working memory is limited, which allows them to remember only two steps of instructions simultaneously*."

Furthermore, teachers emphasized that visual and contextual preferences strongly influence the learning styles of students with intellectual disabilities. Materials that incorporate images, colors, videos, or real objects are often easier to understand than pure text. This is supported by other research findings showing that students with intellectual disabilities tend to have learning styles influenced by visual and contextual preferences, making materials that incorporate images, colors, videos, or real objects easier to understand than pure text. Aisami (2015) [9]; Sirodjovna & Abdumalikovna (2025) [28] found that students with moderate intellectual disabilities were more responsive to visual media such as pictures and videos accompanied by repetition, while research by Lappa & Mantzikos (2021) emphasized that direct observation of visual objects helps them understand information better than verbal explanations alone [10]. Furthermore, studies at PKBM SEHATI also show that concrete media such as posters, props, and videos can increase student engagement and retention among students with intellectual disabilities [29-32]. Thus, the use of visual and contextual media is an essential strategy for learning among children with special needs.

Teacher E Explained:

> "*If there are pictures or videos, they understand more quickly. If it's just text, they get bored quickly and don't understand*."

However, students' knowledge structures remain fragmented and concrete, so they can only recognize facts or objects in isolation, unable to connect the relationships between concepts.

Teacher B Said:

> "*They can memorize the names of objects, but when asked to explain the relationship between objects or ideas, they are confused. They only think about one thing, which doesn't connect them*."

This suggests that students' conceptual abstraction abilities are limited, primarily characterized by concrete-operational thinking. In terms of assessment, teachers generally use a manual, descriptive, and observational approach, without a systematic taxonomy to map students' levels of understanding. They record simple notes such as "understand" or "don't understand," without clear hierarchical indicators.

Teacher F expressed:

> "*So far, we have only written notes saying 'understand' or 'don't understand', but we don't know the depth of our understanding*."

Therefore, teachers felt the need for more adaptive and structured assessment tools that not only assess general abilities but also provide more detailed understanding profiles. The majority of teachers supported the use of a hierarchical taxonomy approach, such as the SOLO Taxonomy, as it was seen as helping to more clearly classify students' understanding.

Teacher F added:

> "*If there were a tool that could directly provide an understanding profile, that would be very helpful*."

Based on these findings, this study was designed as an automated instrument based on the SOLO Taxonomy, which includes five hierarchical levels: pre-structural, uni-structural, multi-structural, relational, and extended abstract. However, this instrument is simplified to accommodate the characteristics of students with intellectual disabilities, namely by using a formative application that can present questions in interactive visual form in the form of images and audio, answer choices with voice or video (if students cannot write yet), one-step instructions with automatic feedback, and local context-based content that is easier to understand. With this approach, it is hoped that the assessment can provide a more precise mapping of students' understanding depth, rather than simply labelling students as "understand/don't understand," so that teachers can design differentiated learning to meet each student's needs.

Based on thematic analysis of the interviews on students with intellectual disabilities' learning characteristics, the following five main themes were obtained in Table **1**:

Quantitative Stage Findings

The quantitative phase of this research involved 30 students with mild intellectual disabilities at SNS-C as respondents. An automated instrument based on SOLO Taxonomy was implemented to map their knowledge structure hierarchically. The instrument's content validity was assessed through expert evaluation using Aiken's V, yielding a score of 0.89, which is categorized as very valid. This indicates that the developed test items align with the theoretical constructions of SOLO Taxonomy and are relevant to the characteristics of students with intellectual disabilities. The instrument's reliability was calculated using the KR-20 formula, yielding a value of 0.82, indicating high reliability. These results demonstrate

Table 1: Summary of Thematic Analysis Resulting from TEACHERS' interviews on Students with Intellectual Disabilities' Learning Characteristics

Main Theme	Description of Findings	Examples of Teachers' Quotes
Linguistic limitations and working memory	Students often struggle to understand long sentences and multi-step instructions.	The instructions must be one at a time; if there are more than two steps, they will get confused.
Dominance of visual and concrete learning styles	Visualizations (images, videos, real objects) speed up students' understanding compared to pure text	If there's a picture, they will immediately understand what it means
Fragmented knowledge	Students memorize individual facts but struggle to connect concepts.	Can name the fruit but can't explain the differences in their functions.
Manual assessment is less systematic	Teachers only record general observations without a structured level of understanding.	We only know whether they understand, not at what level.
The need for taxonomy-based automated assessment	Teachers want assessments based on a hierarchy of understanding with more measurable and adaptive results.	If there were a tool that could directly provide an understanding profile, that would be very helpful.

that the instrument is not only valid in terms of content but also consistently reliable. The distribution of students across SOLO taxonomy levels is shown in Figure **2**.

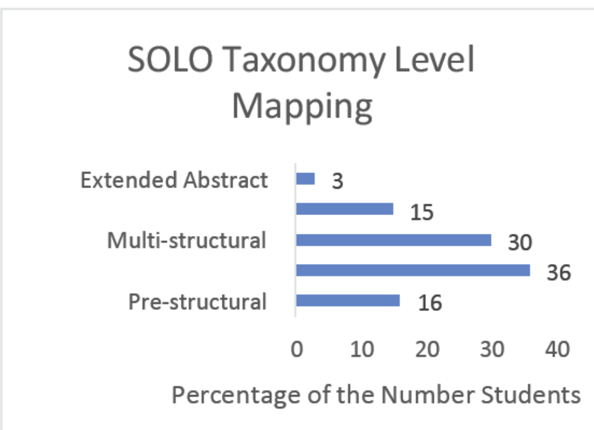

Figure 2: Distribution of students across SOLO taxonomy levels (n = 30).

Figure **2** shows that the majority of students are at the uni-structural (36%) and multi-structural (30%) levels, meaning that most students can recognize basic concepts individually but struggle to integrate relationships between concepts. Meanwhile, 16% of students are at the pre-structural level, indicating minimal understanding and predominantly concrete, linear information processing, with limitations in conceptual abstraction. The studies supporting this claim are Putri *et al.* (2020) [33]; Yıldırım & Karabulut (2023) [34]; Sello *et al.* (2024) [35], who found that the Concrete Pictorial Abstract (CPA) learning strategy was highly effective for students with intellectual disabilities in improving their understanding of mixed concepts in materials science, but required a sequential approach from concrete to abstractconcepts. Additionally, Yildirim &Yıkmış (2022) [36]; Memarian & Doleck (2024) [37]; Sibley *et al.* (2024) [38]; Kaya & Yildiz (2024) [39] reported that a similar approach (Concrete Representational Abstract) significantly helped students with mild intellectual disabilities learn basic addition facts, confirming that their level of understanding was much better when starting from the concrete stage.

DISCUSSION

From a methodological perspective, the use of an exploratory sequential mixed-methods design strengthens the overall rigor of this study. The qualitative phase ensured that the assessment instrument's development was grounded in students with intellectual disabilities' actual learning characteristics. Subsequently, the quantitative phase provided empirical evidence regarding the instrument's psychometric quality. The combined use of Aiken's V for content validation, KR-20 for reliability estimation, and Rasch modelling for item-person calibration enabled a comprehensive evaluation of the instrument. This methodological integration enhances the credibility of the SOLO-AA system as a diagnostic tool for mapping students' knowledge structures in inclusive education contexts.

The findings of this study provide important theoretical insights into the cognitive learning patterns of students with intellectual disabilities. The qualitative evidence gathered from teachers' interviews indicates that these students tend to rely heavily on visual and concrete learning representations, which aligns with previous studies emphasizing the importance of visual learning media in special education contexts [9, 31]. Visual stimuli, such as images, videos, and contextual objects, appear to support students' comprehension by reducing linguistic complexity and facilitating direct cognitive engagement with the learning materials.

Another significant finding concerns the fragmented nature of students' knowledge structures. Many students were able to recognize isolated facts or objects but had difficulty integrating multiple concepts or explaining relationships between ideas. This pattern confirms earlier research suggesting that learners with intellectual disabilities often demonstrate limited conceptual abstraction and tend to process information in discrete units rather than integrated conceptual networks [2, 3]. Within this context, the SOLO taxonomy provides a useful theoretical framework for understanding how students' knowledge structures develop hierarchically. The taxonomy enables educators to identify progressive stages of cognitive development, ranging from pre-structural understanding to extended abstract reasoning. The results of this study show that most students were positioned at the uni-structural and multi-structural levels, indicating that they could recognize individual concepts but had difficulty connecting them relationally. These findings highlight the value of hierarchical assessment models in revealing the depth of student understanding rather than relying solely on binary correct-incorrect evaluations.

Analysis of students with intellectual disabilities' response patterns reveals that picture-based questions, interactive simulations, and open-ended questions are easier to understand. At the same time, the level of difficulty increases in questions that require integration between concepts (Relational) or generalization to a broader context (Extended Abstract). These findings align with existing research, Park & Park (2019) [40]; Widiana *et al.* (2025) [41], who used the Rasch Model on individuals with intellectual disabilities and found a person reliability of 0.73 with an item reliability of 0.76, indicating that response consistency was in the moderate category due to heterogeneity of abilities. Another study by Tassé *et al.* (2016) [42]; Selau *et al.* (2020) [43]; Sheptian *et al.* (2024) [44] confirmed that the item-person map can show the alignment of most items with the respondent's ability range, although some items fall outside the target ability range and are therefore considered more difficult. In addition, the study by Kim & Gray (2024) [45] found that using the Rasch Model, staff who work with individuals with intellectual disabilities demonstrated high person and item reliability but were unable to accurately grasp the meaning of instructions. Only a small proportion of students can reach the Relational level (15%), where they can connect several concepts logically, and even fewer get the Extended Abstract level (3%), which involves the ability to generalize and transfer concepts to new situations.

Beyond its pedagogical value, the SOLO-AA framework also has implications for assessment-informed decision-making in intellectual disabilities contexts. Structured mapping of cognitive responses may help teachers and specialists identify students' conceptual processing patterns, which can inform individualized educational planning (IEP) and targeted intervention strategies. For example, students who consistently perform at the unistructural level may benefit from scaffolded instruction that emphasizes concept linking and relational reasoning. In contrast, students reaching the relational level may be ready for guided generalization tasks. Thus, the SOLO-AA system can complement traditional educational and psychological assessments by providing fine-grained information about conceptual organization, which is relevant for both instructional planning and educational diagnostics.

These findings confirm that students with intellectual disabilities tend to use item-person maps effectively, mapping item difficulty to respondents' abilities. Thus, the instrument's reliability (0.79; moderate) and item reliability (0.91; high) can be understood as resulting from heterogeneous variation in student abilities. At the same time, the item-person map confirmed that most items fit within the range of student abilities, although some require more complex relational analysis.

The use of the SOLO taxonomy as a theoretical framework was crucial in structuring the assessment process in this study. Rather than focusing solely on whether students could provide correct answers, the SOLO framework enabled the assessment to capture different levels of conceptual understanding**.** This approach is particularly important in the context of students with intellectual disabilities, whose learning progression often occurs through gradual cognitive development. The findings demonstrate that most students were positioned at the unistructural and multistructural levels**,** indicating that they were able to recognize individual concepts but experienced difficulty integrating them into a coherent relational understanding. Through the SOLO hierarchy, these variations in understanding could be clearly identified and interpreted. Consequently, the framework provides teachers with a more meaningful perspective on student learning by revealing how knowledge structures evolve. This reinforces the value of SOLO not only as a classification system but also as a diagnostic framework for understanding cognitive development in inclusive education.

The main strength of this finding lies in the automated SOLO-AA's ability to provide a more detailed hierarchical picture of students' understanding, rather than simply a binary "understand/don't understand" result. With this approach, teachers can see more specifically how students recognize, connect, or generalize concepts. Furthermore, the integration of interactive visual media and automated feedback has proven effective in accommodating students with intellectual disabilities' cognitive characteristics, enabling them to be more actively involved in the assessment process. This study also demonstrates the relevance of the Rasch Model as a statistical approach that can simultaneously evaluate the suitability of test items and respondents' abilities, resulting in a more adaptive and measurable instrument.

Beyond its theoretical contributions, this study provides practical guidance for both teachers and assessment developers in designing more inclusive and responsive learning environments. The hierarchical mapping of students' understanding through the SOLO taxonomy enables teachers to identify not only whether students understand a concept but also the depth and structure of their understanding. Such information is essential for implementing differentiated instruction, as teachers can adjust learning strategies according to students' cognitive levels. For example, students identified at the pre-structural and uni-structural levels may benefit from learning activities that emphasize concrete experiences, visual representations, and repetitive practice. Meanwhile, students at the multi-structural level can be supported through tasks that encourage connections between concepts, such as guided comparisons or structured problem-solving activities. For learners approaching the Relational level, instructional strategies may focus on concept integration, relationship explanations, and contextual applications. In this way, the SOLO-AA does not merely measure learning outcomes but functions as a diagnostic tool that supports differentiated teaching practices.

The implications of these findings are significant for the development of assessment and instruction in special education. First, these results can serve as a basis for differentiated learning, in which teachers adapt materials and learning strategies to students' varying levels of understanding. Second, this automated assessment platform, based on the SOLO Taxonomy, can be integrated into ongoing diagnostic and formative evaluations, enabling teachers to monitor student progress in real time. Third, this research opens the door to developing similar instruments that incorporate local cultural contexts to make them more meaningful to students.

The findings also offer important insights for assessment developers, particularly those working in inclusive education contexts. Traditional assessments often rely on uniform task structures that may not adequately reflect the diverse cognitive profiles of students with intellectual disabilities. The SOLO-AA framework demonstrates how assessment items can be organized hierarchically to capture progressively more advanced levels of understanding. By integrating visual prompts, simplified instructions, and contextual tasks, assessment designers can create instruments that are more accessible while still maintaining conceptual rigor. Furthermore, the use of automated systems enables assessments to serve as formative evaluation tools, providing teachers with immediate feedback and enabling continuous monitoring of students' conceptual development. This approach aligns with current best practices in formative assessment, which emphasize ongoing diagnostic feedback rather than one-time summative judgments.

One important contribution of the SOLO-AA system lies in its ability to support diagnostic profiling of students' cognitive understanding. Unlike conventional assessments that primarily categorize responses as correct or incorrect, the SOLO-AA enables a more nuanced analysis of students' knowledge structures. By mapping responses into hierarchical levels of understanding, ranging from pre-structural to relational, the system provides a clearer representation of how students with intellectual disabilities organize and process conceptual information. This diagnostic profiling allows teachers to identify specific patterns of understanding and misconceptions. For instance, students at the uni-structural level may recognize individual concepts but struggle to connect them to related ideas, whereas those at the multi-structural level may understand several concepts but have difficulty integrating them into a coherent structure. Such diagnostic insights provide educators with valuable information about students with intellectual disabilities' cognitive learning profiles.

The SOLO-AA system also supports the multidisciplinary assessment process,which is a fundamental principle in special education. Assessment for students with intellectual disabilities often involves collaboration among multiple professionals, including teachers, special education specialists, psychologists, and therapists. The structured data generated by the SOLO-AA provides a shared reference for these professionals when analyzing students' learning progress. By presenting assessment results in hierarchical cognitive levels, the system facilitates communication among members of the multidisciplinary team. Teachers can interpret classroom learning outcomes, psychologists can relate these outcomes to cognitive development, and therapists can design supportive interventions based on identified learning needs. In this way, the SOLO-AA framework contributes to a more integrated and evidence-based assessment process.

Another important implication of the SOLO-AA outcomes is their potential contribution to the development of individualized educational interventions for students with intellectual disabilities. Because the SOLO framework reveals the depth of students' conceptual understanding, teachers can design instructional strategies that correspond to students' current cognitive levels. For example, students identified at the pre-structural or unistructural may benefit from instructional strategies that emphasize concrete experiences, visual supports, and guided practice. Students at the multi-structural level can be supported through activities that encourage connections between concepts, such as structured comparisons or problem-based tasks. Meanwhile, learners approaching the relational level may engage in learning activities that involve explaining, reasoning, and applying knowledge in new contexts. Through this approach, assessment outcomes are not merely used to measure learning performance but also serve as a foundation for designing targeted, individualized instructional interventions.

The results of this study highlight several best practices for inclusive assessment and instruction. First, assessment instruments should be designed to capture hierarchical levels of understanding, allowing teachers to identify gradual cognitive progression. Second, instructional strategies should incorporate visual and contextual learning support, which have been shown to enhance comprehension among students with intellectual disabilities. Third, integrating automated assessment platforms can facilitate continuous formative evaluation, enabling teachers to monitor student progress and adjust instruction in real time. By combining hierarchical assessment models with adaptive instructional strategies, educators can create learning environments that are more responsive to the diverse cognitive needs of students with intellectual disabilities. Taken together, these findings demonstrate that the SOLO-AA system can serve not only as an assessment tool but also as a diagnostic and instructional support framework. By providing structured insights into students' cognitive development, the system contributes to diagnostic profiling, facilitates multidisciplinary collaboration, and informs the development of individualized learning interventions for students with intellectual disabilities.

For future research, several possible development directions exist. First, this instrument could be tested on a broader population of students with a range of intellectual disabilities (e.g., moderate to severe) to determine its effectiveness across different levels of special needs. Second, longitudinal development is necessary, specifically mapping students' knowledge structures over a more extended period to observe the dynamics of their understanding development. Third, further research could incorporate artificial intelligence (AI) to create more adaptive assessments, for example, by providing questions that automatically adjust based on the level of understanding detected. Finally, ethno-pedagogical content enrichment could be conducted to enhance the connection between assessment materials and students' lived experiences, thereby promoting a more contextual understanding.

From an educational perspective, these findings emphasize the importance of designing learning environments that accommodate students with intellectual disabilities' cognitive strengths and weaknesses. First, instructional materials should incorporate visual and contextual representations, as these formats support comprehension and engagement. Second, teachers need assessment tools that can identify gradual cognitive development, rather than simply categorizing students as "able" or "unable." The SOLO-AA system developed in this study demonstrates how hierarchical assessment frameworks can help teachers more accurately map students' knowledge structures. By identifying whether students operate at the pre-structural, uni-structural, or relational level, teachers can design more targeted and differentiated instructional strategies that support conceptual progression.

CONCLUSION

This study demonstrates that the SOLO-AA system can effectively capture the hierarchical knowledge structure of students with mild intellectual disabilities. By integrating teachers' qualitative insights into a visual, interactive, automated platform, the assessment provides a more nuanced cognitive profile, going beyond simple right/wrong responses. Findings reveal that most students operate at both the unistructural and multistructural levels, validating teachers' observations of their concrete, fragmented knowledge patterns. From a methodological perspective, high content validity (Aiken's V = 0.89), strong reliability (KR-20 = 0.82), and Rasch analysis results confirm the robustness of the SOLO-AA in special education settings.

Pedagogically, the SOLO-AA provides a powerful diagnostic tool for teachers to design differentiated learning pathways tailored to each student's cognitive level. Technologically, this study contributes to the development of a scalable AI-based assessment model that can enhance inclusive practices by personalizing instruction in real time. Future research should expand on this study by testing the system on a broader population with ID, integrating longitudinal tracking to observe cognitive developmental trajectories, and incorporating culturally responsive content. Furthermore, the development of adaptive AI algorithms could enable dynamic, real-time adjustment of task complexity, optimizing individualized learning support for students with diverse needs.

The findings contribute to the theoretical understanding of learning in students with intellectual disabilities by demonstrating how visual-oriented learning preferences, fragmented knowledge structures, and hierarchical cognitive development can be systematically mapped through a SOLO-AA framework. The use of the SOLO Taxonomy as a theoretical foundation allows assessment to move beyond simple correctness measures, enabling educators to interpret students' cognitive development through hierarchical levels of understanding.

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