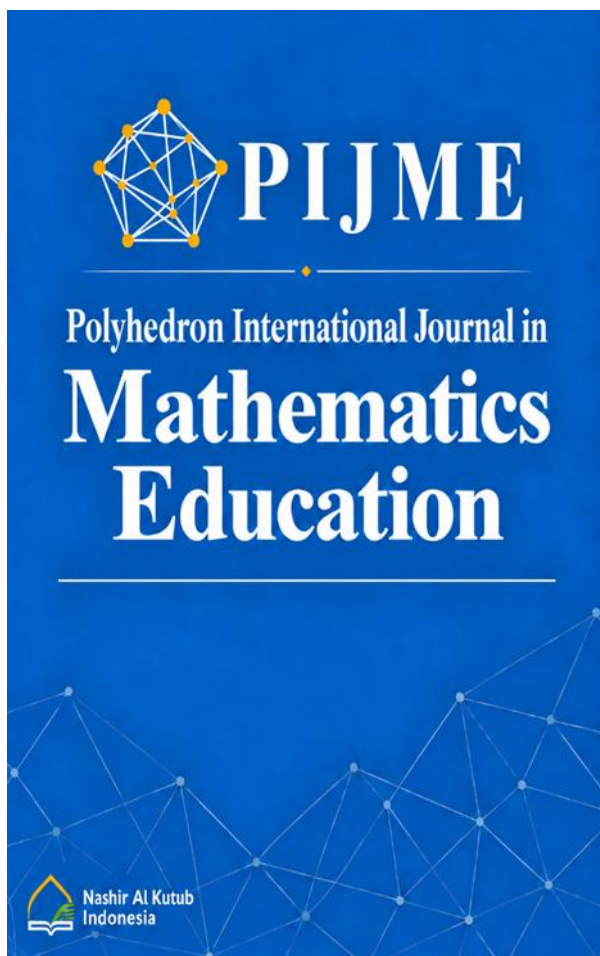




Cognitive barriers and Universal Design for Learning support in understanding number concepts in students with intellectual disabilities

Lutfiah Lutfiah¹, Sudirman Sudirman^{2*}, Endang Wahyuningrum³, Benilda María Cantillo-Rudas⁴

¹Master's Program in Mathematics Education, Postgraduate School, Universitas Terbuka, Jakarta, Indonesia, upayazza@gmail.com

²Master's Program in Mathematics Education, Postgraduate School, Universitas Terbuka, Jakarta, Indonesia, sudirman.official@ecampus.ut.ac.id

³Master's Program in Mathematics Education, Postgraduate School, Universitas Terbuka, Jakarta, Indonesia, endangw@ecampus.ut.ac.id

⁴Institucion Universitaria de Barranquilla, Barranquilla, benilda-m.cantillo-r@up.ac.pa

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Lutfiah Lutfiah¹, Sudirman Sudirman^{2*}, Endang Wahyuningrum³, Benilda María Cantillo-Rudas⁴

¹Master's Program in Mathematics Education, Postgraduate School, Universitas Terbuka, Jakarta, Indonesia, upayazza@gmail.com

²Master's Program in Mathematics Education, Postgraduate School, Universitas Terbuka, Jakarta, Indonesia, sudirman.official@ecampus.ut.ac.id

³Master's Program in Mathematics Education, Postgraduate School, Universitas Terbuka, Jakarta, Indonesia, endangw@ecampus.ut.ac.id

⁴Institucion Universitaria de Barranquilla, Barranquilla, benilda-m.cantillo-r@up.ac.pa

*Correspondence: upayazza@gmail.com

Abstract

Although Universal Design for Learning (UDL) is widely used to support inclusive instruction, how its principles respond to interacting cognitive barriers during number-concept learning remains insufficiently understood. This study examined the barriers experienced by students with intellectual disabilities and how visual media-assisted UDL supported their understanding. An exploratory qualitative multiple-case study involved three students with moderate intellectual disabilities at an inclusive junior high school in Tangerang City, Indonesia. Data comprised classroom observations, interviews with students and supporting informants, student worksheets, and learning documentation. Analysis followed the interactive model of Miles, Huberman, and Saldaña, combining data condensation, data display, and conclusion drawing and verification with source and method triangulation. Four interrelated themes emerged: limited working memory and attention, difficulty understanding abstract concepts, limited generalization, and reliance on concrete representations. Across the cases, multiple means of representation supported connections between quantities and numerals; multiple means of action and expression allowed students to demonstrate understanding through pointing, matching, and manipulating objects; and multiple means of engagement helped sustain participation through focused tasks and guidance. Difficulties persisted when representations changed or concrete support was reduced. These findings suggest that UDL provided a framework for matching instructional support to individual learning demands rather than eliminating cognitive barriers. The account is context-bound and does not establish causal effects or generalizable improvement.

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1. Introduction

Mathematics education plays a crucial role in developing the logical thinking, problem-solving, and decision-making skills needed in everyday life. One of the basic competencies underpinning mathematics learning is an understanding of number concepts, which is a prerequisite for mastering arithmetic, algebra, measurement, and more advanced mathematics. For students with intellectual disabilities, mastery of number concepts is related not only to academic achievement but also to the development of adaptive skills that support daily activities, such as recognizing quantities, using money, telling time, and performing simple calculations. Therefore, examining how students with intellectual disabilities learn number concepts is strategically important for realizing inclusive mathematics education and providing equal learning opportunities for all students.

However, students with intellectual disabilities still face various challenges in learning number concepts. Intellectual disability is characterized by significant limitations in both intellectual functioning and adaptive behavior (American Association on Intellectual and Developmental Disabilities [AAIDD], 2021), and students with this condition commonly show limitations in working memory, attention span, abstraction, and generalization. These limitations matter for mathematics because working memory, attention, and other executive functions contribute substantially to arithmetic performance (Bellon et al., 2019) and constrain how much information learners can process when forming new concepts (Schneider & Stern, 2010). As a result, students with intellectual disabilities often develop mathematical concepts more slowly than their typically developing peers. They frequently have difficulty connecting number symbols with quantities, retaining information during calculations, and transferring learned concepts to new situations. Consequently, mathematics instruction for these students often focuses solely on procedures without fostering deep conceptual understanding, even though conceptual understanding is fundamental to the continued development of mathematical thinking (Fuson, 2019).

Various studies have examined the mathematics learning of students with intellectual disabilities. Browder et al. (2008) and Spooner et al. (2019) synthesized evidence showing that students with moderate and severe intellectual or developmental disabilities can acquire mathematical skills when instruction is systematic, explicit, and supported by concrete and visual materials. Bouck et al. (2017) showed that a concrete-representational-abstract (CRA) sequence helped students with intellectual disability solve change-making problems, underscoring the importance of a planned transition from manipulatives to symbols, while Root et al. (2017) reported that schema-based instruction with concrete and virtual manipulatives supported the mathematical problem solving of students with autism. Fuson (2019) and Clements et al. (2023) further emphasized that number understanding develops when teachers systematically relate quantities, visual images,

words, and mathematical symbols. In parallel, the Universal Design for Learning (UDL) framework proposes that barriers to learning can be reduced by designing instruction that offers multiple means of representation, action and expression, and engagement (CAST, 2018; Meyer et al., 2014). Reviews by Rao et al. (2014), Ok et al. (2017), Capp (2017), and Almeqdad et al. (2023) indicate that UDL-based instruction generally has positive effects on access and learning, although most of the reviewed studies measured learning outcomes rather than learning processes.

Although these studies make important contributions, three limitations can be identified. First, the UDL studies synthesized by Rao et al. (2014), Ok et al. (2017), Capp (2017), and Almeqdad et al. (2023) mainly evaluated whether UDL improves outcomes or participation; few describe what happens in students' reasoning while UDL-based support is provided, and very few have focused specifically on students with intellectual disabilities learning early number concepts. Second, intervention studies for students with intellectual disabilities (e.g., Bouck et al., 2017; Browder et al., 2008; Spooner et al., 2019) typically examine a single instructional package or skill, and cognitive barriers such as limited working memory, attention, abstraction, or generalization are usually discussed as separate characteristics rather than as factors that operate together within the same task (Bellon et al., 2019; Schneider & Stern, 2010). Third, Indonesian studies on inclusive education have mostly addressed policy, school management, or general teaching strategies (e.g., Kontesa et al., 2026; Pujiaty, 2024; Yunita & Subagya, 2025) and have rarely analyzed number-concept learning at the level of students' thinking processes. Consequently, it remains unclear how these cognitive barriers interact while students with intellectual disabilities construct number concepts and which aspects of each UDL principle respond to which barrier. This is the research gap that the present study addresses.

To address this gap, this study analyzes the relationship between the cognitive barriers of students with intellectual disabilities and the support provided by UDL principles while the students learn number concepts with visual media. It differs from previous research in three ways. First, whereas prior UDL reviews and intervention studies mainly report whether outcomes improved, this study examines the learning process, that is, how students respond to specific supports during number tasks. Second, instead of treating cognitive barriers as isolated characteristics, it examines how they co-occur within the same learning episodes. Third, it maps each UDL principle onto the specific barriers it appears to address, thereby linking a cognitive-barrier analysis with a pedagogical-design analysis within one multiple-case study. Given the small number of cases, the study is intended to offer an in-depth, context-bound account that can inform, rather than be generalized to, inclusive mathematics practice.

Accordingly, this study aims to (1) describe the cognitive barriers experienced by students with intellectual disabilities in understanding number concepts and (2)

analyze how the principles of UDL, implemented through visual media-assisted learning, support these students' understanding of number concepts. Two research questions guided the study: (RQ1) What cognitive barriers do students with intellectual disabilities experience when learning number concepts? (RQ2) How do the three UDL principles support their understanding of number concepts during visual media-assisted learning? The findings are expected to contribute to research on inclusive mathematics education and to provide a basis for teachers in designing more adaptive, flexible, and appropriate learning for students with intellectual disabilities.

2. Method

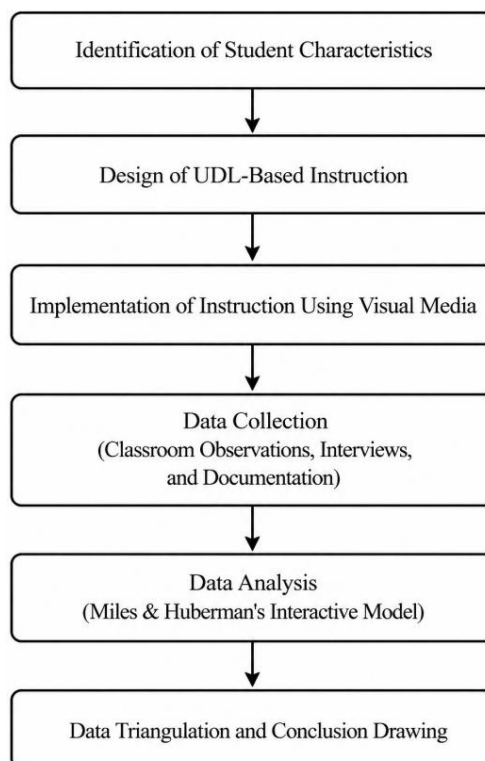
2.1 Research Design

This study used a qualitative approach with an exploratory multiple-case study design (Yin, 2018). An exploratory case study was selected because the phenomenon examined, namely the interplay between the cognitive barriers of students with intellectual disabilities and UDL-based support during number-concept learning, has rarely been studied, and its boundaries with the classroom context are not clearly evident. According to Yin (2018), case studies are appropriate for answering "how" and "why" questions about contemporary phenomena in their real-life context when the researcher has little control over events, which corresponds to both research questions. Each student was treated as a case, bounded by one inclusive school and one series of number-concept lessons, and cross-case comparison was used to identify shared and individual patterns (Creswell & Poth, 2018). This design allowed the interaction among students' cognitive characteristics, learning strategies, and the use of visual media to be examined in depth.

The research was conducted in five stages: (1) identifying the characteristics of the participants based on assessment results and recommendations from the special guidance teacher (*guru pembimbing khusus*, GPK); (2) designing number-concept lessons based on UDL principles using visual media; (3) implementing the lessons and collecting data through observation, interviews, and documentation; (4) analyzing the data thematically using the interactive model of Miles et al. (2014); and (5) drawing conclusions through triangulation of data sources. The research flow is shown in Figure 1.

Figure 1

Research Implementation Flow



2.2 Participants

The participants were three students with moderate intellectual disabilities (pseudonyms Naya, Rama, and Ina; aged 13–14 years) enrolled in an inclusive public junior high school (sekolah menengah pertama, SMP) in Tangerang City. They were selected through purposive sampling using four criteria: (1) a documented diagnosis of moderate intellectual disability in a psychological assessment report held in the school records, used to establish eligibility rather than as a new diagnostic assessment by the researchers; (2) regular participation in mathematics lessons in an inclusive class; (3) a recommendation from the GPK indicating that the student was still developing basic number concepts (number recognition, one-to-one correspondence, and simple addition); and (4) parental consent to participate. The three students were considered information-rich cases (Patton, 2015) because, while sharing the same diagnostic category and learning in the same class, they displayed different learning characteristics (Table 1), which enabled a cross-case comparison of how cognitive barriers and UDL support played out for different learners.

Table 1

Characteristics of the Participants

Participant	Age (years)	Disability category	Learning characteristics
Naya	14	Moderate intellectual disability	Recognizes numbers through concrete objects and number cards
Rama	13	Moderate intellectual disability	Understands addition using colored sticks
Ina	13	Moderate intellectual disability	Counts using real objects and fingers

Note. All names are pseudonyms.

In addition to the students, the mathematics teacher, the GPK, and the parents were involved as supporting informants. Involving these informants aimed to obtain comprehensive data on the students' learning characteristics, the learning process, and the development of their understanding of number concepts from multiple perspectives.

2.3 Data Collection

Data were collected through observation, semi-structured interviews, and documentation. Observations were conducted during UDL-based number-concept lessons using visual media to identify cognitive barriers, students' responses to learning, and the teacher's implementation of UDL principles. During the observations, the first author used an observation sheet containing indicators of student learning activities, the use of visual media, student engagement, and the forms of learning support provided by the teacher, and recorded additional field notes.

The semi-structured format gave the researchers a question guide while still allowing informants to explain their experiences in greater depth. Interviews were conducted with the mathematics teacher, the GPK, the parents, and the students. Examples of questions asked to the teachers included "What obstacles do students most often experience when understanding number concepts?", "How does the use of visual media help students understand the material?", and "How are UDL principles applied during the learning process?" The students were asked questions such as "Do you find it easier to learn using pictures or real objects?" and "What part do you find most difficult when learning to count?"

Documentation served as supporting data and included student worksheets (*lembar kerja peserta didik*, LKPD), student work, lesson materials, photographs of learning activities, and observation notes. The use of multiple data collection techniques enabled triangulation, thereby increasing the credibility of the findings.

The observed lessons addressed number recognition, one-to-one correspondence, and simple addition. Interviews with the mathematics teacher, the

GPK, parents, and students complemented the classroom observations by providing different perspectives on students' responses to number tasks and instructional support. The observation sheet and interview guides were organized around the three UDL principles (CAST, 2018) and the cognitive demands of number learning discussed in the literature (Bellon et al., 2019; Fuson, 2019; Schneider & Stern, 2010). Observation records, interview accounts, and student work were compared to identify convergence and differences between what students did during lessons and how informants described their learning. Quotations are presented in English.

2.4 Data Analysis

Data analysis followed the interactive model of Miles et al. (2014), comprising data condensation, data display, and conclusion drawing and verification, and was carried out iteratively during and after data collection. In the condensation stage, field notes, interview transcripts, and documents were read repeatedly and coded. Initial codes were generated deductively from a start list derived from the research questions (e.g., working memory, attention, abstraction, generalization, and the three UDL principles; CAST, 2018) and inductively from recurring behaviors in the data (e.g., "recounts from the beginning," "asks for reconfirmation," "confused when the media change," and "returns to finger counting"). Related codes were grouped into categories, and categories were merged into themes through constant comparison across data sources and across the three cases. For RQ1, this process yielded four cognitive-barrier themes; for RQ2, the codes were organized into three categories corresponding to the UDL principles and linked to the barriers they addressed.

In the data display stage, the themes were organized into case-by-theme matrices, tables, and figures (Tables 2–4 and Figures 3 and 8) so that within-case and cross-case patterns could be compared systematically. Coding was conducted by the first author and independently checked by the second author; disagreements concerning code assignment or theme boundaries were discussed until consensus was reached, and the third author reviewed the final theme structure. To reduce interpretive bias, the researchers wrote analytic memos, searched for disconfirming evidence (e.g., episodes in which a student succeeded without concrete media), and discussed preliminary interpretations with the mathematics teacher and the GPK. Trustworthiness was further supported through source triangulation (teacher, GPK, parents, and students) and method triangulation (observation, interviews, student worksheets, and documentation) (Creswell & Poth, 2018; Lincoln & Guba, 1985).

Because the study is qualitative, the tables and figures are not statistical measurements but analytic summaries of the coded data, prepared using two conventions. First, in Figure 3 the unit of counting is the data-collection method category in which a theme was coded at least once, namely observation, interviews (teacher, GPK, parent, or student), student worksheets (LKPD), and photographic documentation, giving a maximum value of 4 per theme. Second, the intensity ratings

in Table 2 and Figure 8 were assigned for each student and each barrier by researcher consensus using a four-level qualitative rubric: 1 (*low*) = the barrier was coded rarely, in only one data source, and resolved without teacher support; 2 (*moderate*) = the barrier was coded occasionally in at least two data sources and resolved after a brief prompt; 3 (*high*) = the barrier was coded repeatedly across sessions and in at least two data sources and required repeated scaffolding; and 4 (*very high*) = the barrier was coded in almost every observed session and in at least three data sources and persisted despite scaffolding. These ratings describe relative patterns within the three cases and should not be interpreted as psychometric scores.

2.5 Ethical Considerations

Because the participants were minors with intellectual disabilities, specific ethical safeguards were applied. Research permission was obtained from the school principal. Parents or guardians received verbal and written explanations of the objectives, procedures, voluntary nature of participation, and their right to withdraw at any time, and they signed informed consent forms, including separate consent for the publication of photographs. Student assent was obtained in simple language with the support of the GPK before each data collection activity; students were told that they could stop or decline at any time, and signs of discomfort or fatigue were treated as withdrawal of assent for that session. Observations took place during regular lessons so that learning time was not reduced, and student interviews were short, held in a familiar room, and accompanied by the GPK. All names are pseudonyms, identifiable photographs require separate publication consent and de-identification, and raw data were stored on password-protected devices accessible only to the research team.

3. Results and Discussion

3.1 Results

This section reports the cognitive barriers experienced by students with intellectual disabilities in understanding number concepts (RQ1) and how UDL principles, implemented with visual media, supported their thinking processes during learning (RQ2). Data were obtained from classroom observations; interviews with the mathematics teacher, the GPK, parents, and students; and documentation of learning activities and student worksheets. The analysis followed the interactive model of Miles et al. (2014), comprising data condensation, data display, and conclusion drawing and verification, with triangulation across data sources.

3.1.1 Cognitive Barriers of Students With Intellectual Disabilities in Understanding Number Concepts

The analysis showed that the three students (Naya, Rama, and Ina) differed in the specific characteristics of their cognitive barriers but showed relatively consistent patterns during the learning process. Four main themes emerged: (1) limited working memory and attention, (2) difficulty understanding abstract concepts, (3) limited

generalization of concepts, and (4) reliance on concrete representations. Table 2 summarizes the profile of these barriers for each student.

Table 2

Cognitive Barrier Profiles of the Three Students

Cognitive barrier	Naya	Rama	Ina	Triangulation evidence
Working memory and attention	Often forgets calculation results; easily distracted	Recounts repeatedly; loses focus on long tasks	Easily forgets instructions; counts hastily	Observation, teacher interviews, student worksheets, documentation
Abstraction	Needs concrete objects	Has difficulty understanding symbols without media	Understands pictures better than symbols	Observation, interviews, student worksheets, documentation
Generalization	Has difficulty when the media change	Needs repeated examples	Is confused when the form of the question changes	Observation, interviews, student worksheets
Reliance on concrete representations	Very high (4): needs objects paired with number cards	High (3): relies on colored sticks for addition	Very high (4): returns to real objects and fingers	Observation, interviews, student worksheets, documentation

Table 2 shows that all three students displayed a similar set of cognitive barriers, although the strength with which each barrier appeared differed across students according to the rubric described in the Data Analysis section. All three students needed concrete or visual support for abstraction; reliance on concrete representations was summarized as high to very high, whereas limitations in working memory and attention affected their ability to retain numerical information during multi-step tasks. These differences indicate that the thinking characteristics of students with intellectual disabilities are individual and therefore require flexible learning support tailored to each student's needs.

The first barrier was limited working memory and attention. During the lessons, the three students often lost focus when an activity lasted a long time. They could recognize number symbols at the beginning of an activity but had difficulty retaining numerical information when they had to perform several sequential steps. As a result, they often repeated the calculation from the beginning to confirm their results. The mathematics teacher and the GPK also reported that the students were easily distracted by their surroundings and needed repeated instructions and step-by-step guidance throughout the lessons. Observations showed that Naya often asked for reconfirmation before giving an answer, Rama restarted his calculation when he lost the number sequence, and Ina tended to count hastily, which led to several errors. The mathematics teacher described this pattern as follows:

Students are easily distracted by their surroundings. They also get bored quickly and often lose focus. Because of this, they need extra time to understand and retain the concepts in the material they have just learned. (Interview, mathematics teacher)

This finding is consistent with the cognitive perspective of Schneider and Stern (2010), who explain that the limited capacity of working memory constrains how much information learners can process at one time and therefore shapes how new concepts are formed. The teacher responded to this barrier by designing short, focused learning activities rich in visual stimuli.

The second barrier was difficulty understanding abstract concepts. All three students demonstrated better understanding when number concepts were presented through concrete objects, pictures, or number cards than when only mathematical symbols were used. During the observations, Rama completed addition more easily using colored sticks, Naya correctly matched the number of objects to number cards, and Ina grasped the relationship between quantities and number symbols more easily by counting objects directly. Conversely, when concrete media were reduced and only number symbols were used, the students' performance declined, and they needed teacher assistance to continue their reasoning.

The third barrier was limited generalization of concepts. The students were able to complete tasks when the media were the same as in the previous example but struggled when the visual representation changed, even though the underlying concept remained the same. This pattern was most evident for Ina, who counted correctly using familiar colored blocks but became confused when the same quantity was presented on picture cards. This indicates that the students' understanding still depended heavily on the context in which the concept was first learned, so the transfer of knowledge to new situations had not yet developed optimally.

The fourth barrier was a strong reliance on concrete representations. Visual aids and manipulatives served as the primary supports for understanding number concepts. When the teacher began reducing visual aids to encourage students to use mathematical symbols independently, the performance of all three students declined: they completed tasks more slowly, asked for help more frequently, or reverted to counting on their fingers or using objects around them. These findings suggest that the transition from concrete experiences to symbolic representations still requires gradual and sustained support. This finding was reinforced by the student interviews:

I get confused when I'm asked to count just by looking at written numbers. I often don't know the answer. I can count right away and find the correct answer when the teacher helps me with a ball or another real object. (Interview, Rama)

Figure 2

Rama Solving an Addition Problem With the Help of Colored Sticks



Figure 2 shows Rama working on an addition problem using colored sticks as a concrete manipulative. Rama understood addition more easily when numbers were presented in a form that could be seen, touched, and counted directly. In this activity, the colored sticks served as a concrete representation of quantity, so addition was understood not merely as a combination of number symbols but as the joining of tangible, visually observable objects. This is consistent with the interview data, which showed that Rama found counting easier when using pictures or concrete objects.

Table 3

Synthesis of the Cognitive Barriers of Students With Intellectual Disabilities in Understanding Number Concepts Through Visual Media-Assisted UDL

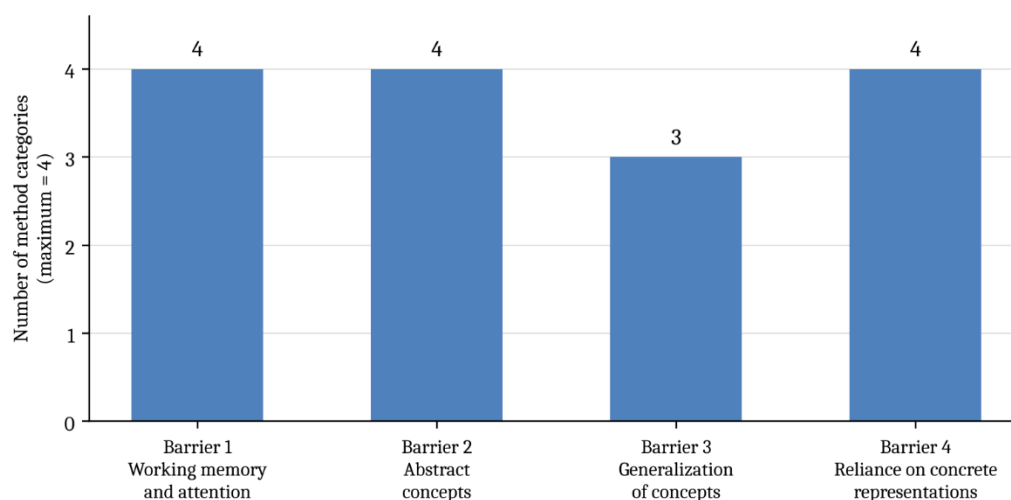
Cognitive barrier theme	Indicators	Students showing the barrier	Observation and interview evidence	UDL-based learning response
Limited working memory and attention span	Easily loses focus, forgets the order of numbers, repeats the counting process	Naya, Ina, Rama (situational)	Naya needs repeated confirmation; Ina counts hastily; the teacher reports that students are easily distracted and get bored quickly	Short activities, repetition, gradual use of visual aids
Difficulty understanding abstract concepts	Has difficulty understanding arithmetic operations without visual aids	Naya, Rama, Ina	Rama understands numbers more easily through concrete objects; students have difficulty understanding symbols without visual media	Multiple means of representation (pictures, large symbols, concrete objects)

Cognitive barrier theme	Indicators	Students showing the barrier	Observation and interview evidence	UDL-based learning response
Limited generalization of concepts	Has difficulty transferring concepts to different visual forms	All three students; most evident for Ina	Students are confused when media formats change and need consistent repetition	Scaffolding and a gradual increase in complexity
Reliance on concrete representations	Comprehension decreases when visual aids are reduced	Rama, Ina, Naya	Students still rely on concrete objects and are not yet independent in using abstract symbols	Gradual reduction (fading) of visual aids

Table 3 suggests that the students' main difficulties lay not in a complete inability to grasp number concepts but in limitations in retaining information, transferring concepts, and constructing mathematical abstractions independently. Within these three cases, the UDL-based responses listed in the last column appeared to function as adaptive supports that helped students find learning paths aligned with their individual cognitive profiles.

Figure 3

Corroboration of the Four Cognitive Barriers Across Data-Collection Methods



Note. Values indicate the number of data-collection method categories (observation, interviews, student worksheets, and documentation; maximum = 4) in which each theme was coded at least once. Barrier 1 = limited working memory and attention; Barrier 2 = difficulty understanding abstract concepts; Barrier 3 = limited generalization of concepts; Barrier 4 = reliance on concrete representations.

Figure 3 shows that three barriers, namely limited working memory and attention (Barrier 1), difficulty understanding abstract concepts (Barrier 2), and reliance on concrete representations (Barrier 4), were identified in all four data-collection method categories, whereas limited generalization of concepts (Barrier 3)

was identified in three categories (observation, interviews, and student worksheets) but not in the photographic documentation, which captured single moments rather than transfer across representations. Because the values count method categories rather than episodes or participants, they indicate how well each theme was corroborated across methods, not how often or how severely it occurred.

Triangulation across observations, interviews, student worksheets (LKPD), and documentation thus showed that all four barriers were corroborated by multiple methods and sources. Although their intensity varied across students, the pattern suggests that the students' difficulties lay not in an inability to grasp number concepts but in limitations in retaining information, constructing abstractions, transferring concepts, and using mathematical symbols independently. Accordingly, the contribution of UDL should be judged not by whether cognitive barriers disappear but by whether it reduces cognitive load and widens students' access to the process of understanding number concepts.

3.1.2 The Role of Universal Design for Learning Principles

The findings also show that applying the UDL principles provided tangible support for understanding number concepts. The three principles did not work in isolation but complemented one another in helping students access information, express their understanding, and maintain engagement throughout the lessons.

Among the three principles, multiple means of representation was a recurrent form of support, and it was evident for all three students. For Naya, the teacher paired number cards with countable objects, and she matched quantities to numerals correctly when both were present (Figure 5; observation notes). For Rama, colored sticks allowed him to model addition, a support he described himself in the interview quoted above (Figure 2). For Ina, a visual worksheet combined with concrete media enabled her to match sets of objects with number symbols (Figure 4). These episodes link the representation principle to a specific learning demand: coordinating a visible quantity with its corresponding numeral. Across these episodes, the students' attention and responses increased when the material could be directly observed and manipulated and decreased when only written symbols were presented.

The students developed an understanding of number concepts more easily when information was presented through various representations than when only number symbols or verbal explanations were used. The teacher combined number cards, pictures, concrete objects, color markers, and interactive media so that the students could build a more concrete connection between number symbols and quantities. Observations revealed that all three students were more responsive and engaged when information was presented visually and could be observed directly.

Figure 4

Ina Completing a Student Worksheet (LKPD) With the Help of Concrete Media



Figure 4 shows Ina matching the number of objects with number symbols using a visual worksheet supported by concrete media. This activity illustrates the UDL principle of multiple means of representation, as the concept of number was presented in more than one form. In this lesson, number symbols were not presented abstractly but were paired with pictures, colors, and concrete objects that Ina could count directly. This varied presentation helped Ina understand the relationship between the number of objects and number symbols more meaningfully.

The activity also reflects the principle of multiple means of action and expression, because Ina could demonstrate her understanding not only through verbal responses but also by pointing, counting, matching, and selecting the appropriate number symbols on the worksheet. For Ina, who had difficulty with verbal expression, these response options provided a more appropriate way to demonstrate her understanding of number concepts.

From the perspective of multiple means of engagement, the colorful visual media and concrete objects also helped sustain Ina's attention and engagement throughout the lesson. Presenting the material concretely and in a directly observable form brought the counting activity closer to Ina's own experience, which made it easier for her to focus, stay interested, and complete the task. Thus, Figure 4 not only captures Ina's learning activity but also illustrates how the UDL approach facilitated her gradual transition from concrete experiences to number symbols.

Figure 5

Naya Naming the Numbers Written on Number Cards



Figure 5 shows Naya participating in a learning activity in which number cards were used to help her understand the concept of number. This situation illustrates the principle of multiple means of representation, namely presenting information in a more concrete, visual, and accessible form. For Naya, number cards and concrete objects presented numbers in a form that could be seen, touched, and observed directly, so number symbols were understood not merely as abstract symbols but as representations of real quantities. In this way, Naya more easily built connections among numbers, number sequences, and the quantities of the objects she observed.

Overall, the results indicate that the cognitive barriers experienced by students with intellectual disabilities persisted during learning, but visual media-assisted UDL helped mitigate their impact by providing multiple forms of representation, alternative ways of expressing understanding, and strategies for sustaining engagement. These findings suggest that flexible and responsive instruction gives students greater opportunities to build an understanding of number concepts according to their individual needs and cognitive profiles.

3.2 Discussion

3.2.1 Interacting Cognitive Barriers in Number-Concept Learning

The results indicate that the main barriers experienced by students with intellectual disabilities in understanding number concepts are limited working memory and attention, difficulty understanding abstract concepts, limited generalization of concepts, and reliance on concrete representations. These four barriers did not appear as stand-alone difficulties but interacted with one another as the students developed mathematical understanding. Understanding number concepts is therefore a complex process for these students, because limitations in cognitive functioning affect how they receive, store, process, and reuse numerical information.

Barriers related to working memory and attention were among the most consistently corroborated across data sources (Figure 3). All three students tended to

lose focus easily, repeat the calculation process, and require repeated reinforcement to retain numerical information. This indicates that the students were able to recognize number symbols and quantities but had difficulty retaining this information when they had to carry out several sequential steps. As a result, a conceptually simple calculation became more demanding because the students had to remember the number sequence, maintain attention to the task, and coordinate each step of the solution at the same time.

Figure 6

Rama Recounting the Colored Sticks After Losing the Counting Sequence and Receiving Reinforcement From the Teacher



Figure 6 shows that Rama still needed teacher assistance to maintain the counting sequence. This indicates limitations in working memory and attention, which required him to repeat the counting process to obtain the correct result. This finding is consistent with Schneider and Stern (2010), who explain that the limited capacity of working memory constrains learners' ability to hold several pieces of information simultaneously while completing a task. It also aligns with cognitive load theory as elaborated by Sweller et al. (2019): because working memory capacity is limited, the more information that must be processed simultaneously, the more likely learning performance is to decline. In this study, these limitations were apparent when students had to count objects, remember interim results, and then connect them to number symbols in a single sequence of activities. This helps explain why the students often recounted from the beginning even after they had obtained the correct answer.

Beyond working memory, abstraction was a major challenge in understanding number concepts. All three students grasped concepts more easily when numbers were presented through concrete objects, pictures, number cards, or other visual media. Conversely, their performance declined when the teacher used only mathematical symbols or verbal explanations without visual support. These findings suggest that number symbols do not carry stable meaning for these students unless they are connected to concrete experiences.

These results are consistent with Bruner's (1966) theory of representation, which holds that concept formation proceeds through enactive, iconic, and symbolic modes. For students with intellectual disabilities, the movement from concrete experience to symbols appears to be slower than for typically developing peers, so visual representations can serve as a bridge for constructing mathematical meaning. Therefore, number symbols should be treated not as the starting point of learning but as the outcome of a representational process that develops gradually through meaningful learning experiences.

This finding is also consistent with Vygotsky's (1978) concept of the zone of proximal development (ZPD), which holds that learners' thinking develops when they receive appropriate support from more capable others. In this study, visual media, concrete objects, teacher guidance, and repeated instructions served as scaffolding that enabled the students to understand the relationship between quantities and number symbols. This support allowed the students to work within their cognitive limitations so that concept formation could proceed gradually.

The next barrier was limited generalization of concepts. The students were able to complete tasks when the form of representation was the same as in the previous example but struggled when the visual form changed, even though the mathematical concept remained identical. This suggests that their understanding remained strongly tied to the context in which the concept was first learned. A change in presentation therefore appeared to increase the support needed to recognize the same quantity-symbol relationship; the study does not directly establish the structure of the students' mental representations.

This pattern is consistent with Bouck et al. (2017), whose CRA-based instruction for students with intellectual disability explicitly sequenced concrete, representational, and abstract stages rather than assuming spontaneous transfer, and with the syntheses of Browder et al. (2008) and Spooner et al. (2019), which indicate that students with moderate and severe disabilities acquire mathematical skills most reliably when instruction is systematic and includes planned practice with varied materials. Hence, varied representations serve not only as a medium for conveying information but also as a strategy for extending students' ability to connect the same concept across different contexts.

At the same time, this study shows that concrete representations play a dual role. Real objects, pictures, and manipulatives helped the students understand number concepts in the early stages of learning. Continued use of concrete media should not itself be treated as a failure to learn. In these cases, difficulty arose when students had to connect supported performance with symbolic tasks, indicating a need for explicit bridging rather than premature withdrawal of support. Therefore, the primary challenge in teaching mathematics to students with intellectual disabilities is not

choosing between concrete media and abstract symbols but managing the transition between the two so that students can gradually build more independent understanding.

These results are consistent with Root et al. (2017), Fuson (2019), and Clements et al. (2023), who emphasize the importance of concrete and visual representations as a basis for developing number concepts. In addition, the present cases suggest that concrete media should be viewed not solely as learning aids but as part of a representational development process that needs to be followed by a gradual reduction of support toward the use of mathematical symbols.

Figure 7

Naya Matching Concrete Objects With Number Cards to Understand Number Symbols

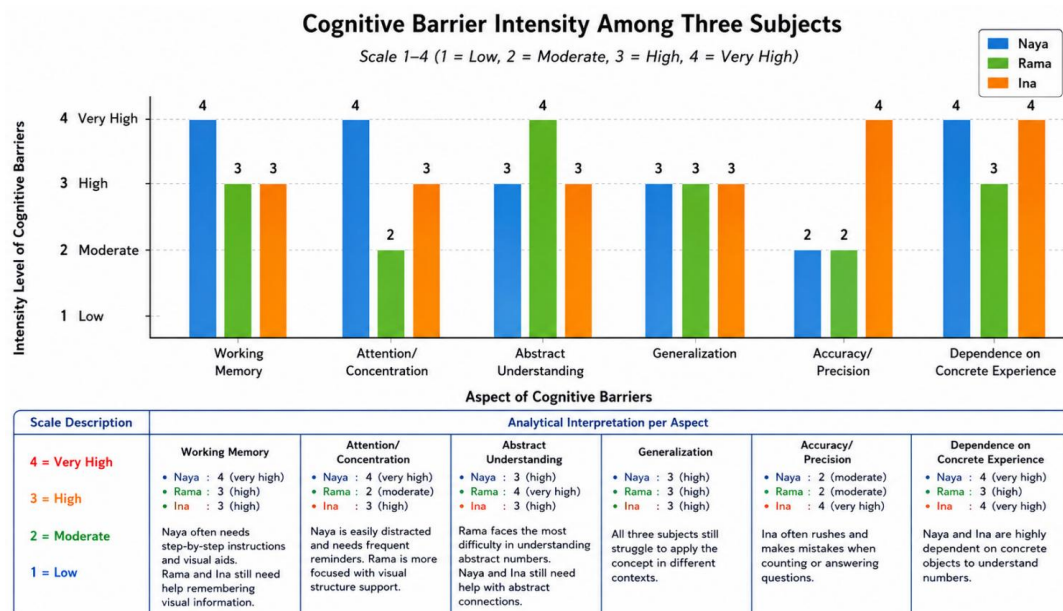


Figure 7 shows that Naya could understand number symbols only when they were accompanied by concrete representations, indicating that her abstraction process still required visual support.

To clarify the variation in cognitive barriers among the three students, the intensity of each barrier aspect, rated using the four-level rubric described in the Data Analysis section, is visualized in Figure 8. In this figure, working memory and attention are shown separately, and accuracy (precision) is shown as an additional aspect that reflects the hasty counting errors coded under Barrier 1. The figure is not intended as a stand-alone quantitative measurement but as an analytic representation of the qualitative findings obtained from observations, interviews, and documentation. It shows which aspects were most pronounced for each student and provides a more complete picture of the cognitive barrier profiles of students with intellectual disabilities learning number concepts through visual media-assisted UDL.

Figure 8

Intensity of Cognitive Barriers in the Three Students (Qualitative Rubric Ratings)



Overall, Figure 8 shows that the cognitive barriers of the three students differed not only in intensity but also in emphasis. This confirms that difficulties in understanding number concepts among students with intellectual disabilities should not be viewed as a uniform impairment but as a combination of limitations in working memory, attention, accuracy, abstraction, and generalization, together with reliance on concrete experiences. Therefore, UDL-based instruction needs to be designed flexibly and individually to respond more appropriately to each student's barrier profile.

In the context of UDL, these findings also suggest that visual media-assisted UDL did not eliminate the students' cognitive barriers but mitigated their impact. UDL made information more accessible, provided more flexible response options, and sustained student engagement throughout the learning process; it did not, however, remove working memory limitations, abstraction difficulties, or generalization problems. The role of UDL in this study is therefore better understood as compensatory and facilitative, helping students learn within their existing limitations rather than eliminating them. This distinction is important to avoid unrealistic expectations of UDL implementation.

In sum, the cognitive barriers to understanding number concepts among these students with intellectual disabilities included limitations in working memory, attention, accuracy, abstraction, and generalization, together with reliance on concrete experiences. These barriers were interconnected and affected the overall process of understanding numbers. Mathematics instruction for students with intellectual disabilities therefore needs to be designed not only to convey content but also to

manage cognitive load, strengthen representational transitions, and provide repeated, structured, and flexible learning support.

3.2.2 The Role of Universal Design for Learning in Supporting the Thinking Processes of Students With Intellectual Disabilities

The results show that visual media-assisted UDL provided tangible support for the thinking processes of students with intellectual disabilities as they learned number concepts. This support came not solely from the visual media themselves but from a learning design that adapted to each student's cognitive characteristics by providing multiple ways to acquire information, express understanding, and sustain engagement. Thus, the value of UDL in this study lies not in the number of media used but in its capacity to create a learning environment that responds to each student's needs.

Multiple means of representation was consistently evident across the three cases. Presenting number concepts through a combination of concrete objects, number cards, pictures, colors, and visual worksheets helped the students build more meaningful relationships between quantities and number symbols. This variety of representations allowed the students to understand concepts through pathways suited to their thinking characteristics, so that abstraction could occur more gradually. For these students, visual representation was not merely a supplement to learning but a primary means of constructing mathematical meaning.

These results are consistent with the UDL guidelines (CAST, 2018), which position representation as an initial gateway to learning. According to CAST (2018), learners differ in how they perceive and comprehend information, so teachers need to provide multiple forms of presentation to minimize learning barriers. In this study, visual media appeared to reduce the burden of abstraction, which was one of the main barriers to understanding number concepts. With clearer connections among concrete objects, pictures, and mathematical symbols, the students could build more stable mental representations before moving on to symbolic understanding.

Beyond access to information, flexibility in demonstrating understanding (multiple means of action and expression) also played an important role in the students' thinking processes. The three students demonstrated their understanding in different ways: Naya found it easier to show her answers by pointing to and matching number cards, Rama demonstrated his understanding by manipulating colored sticks during arithmetic operations, and Ina performed better when allowed to count with concrete objects rather than explain verbally. These findings suggest that limited expressive language does not necessarily reflect limited conceptual ability. Conversely, when teachers provide a variety of response formats, students' mathematical understanding can emerge more authentically.

These findings support the view expressed in the UDL guidelines (CAST, 2018) that students' abilities should not be assessed through a single mode of response. Flexibility in how students express understanding allows teachers to obtain a more

accurate picture of their thinking processes. In mathematics instruction for students with intellectual disabilities, opportunities to manipulate objects, select number cards, arrange numbers, or use counting aids are part of the thinking process itself, not merely variations in learning activities.

This study also shows that multiple means of engagement played an equally important role in supporting the development of number concepts. Student engagement increased when learning took place in a safe and engaging environment that offered opportunities for gradual success. Concrete media, positive reinforcement from the teacher, manipulative activities, and consistent guidance helped the students maintain attention throughout the lessons. These findings indicate that affective and motivational aspects are closely related to the development of thinking processes, especially for students who lose focus easily and have limited working memory.

These findings are consistent with the review by Rao et al. (2014), who found that studies of universal design educational models generally reported positive outcomes, including improved access and participation for learners with disabilities, while noting that the evidence base was still limited. They also align with the content analysis by Al-Azawei et al. (2016), which reported that most of the reviewed UDL studies documented positive effects on the learning process and learners' experiences, not only on achievement. In the present study, engagement was an important condition that enabled the students to sustain attention for longer periods and thus to work with number concepts more productively.

When the three UDL principles of representation, action and expression, and engagement are analyzed together, they appear not to operate in isolation but to form a mutually reinforcing pedagogical mechanism. Diverse representations help students acquire information through the most accessible pathways. Once concepts begin to form, flexibility in expressing understanding allows teachers to identify students' conceptual abilities more authentically. Sustained engagement, in turn, helps students maintain attention so that concept formation can continue. This interrelationship suggests that successful UDL implementation depends not on any single component but on integrating all three principles within a coherent learning design.

Compared with previous research, this study offers a process-oriented perspective. Most earlier studies focused on the effectiveness of UDL in improving learning outcomes (e.g., Almeqdad et al., 2023; Capp, 2017; Ok et al., 2017) or on a single instructional sequence, such as CRA, for students with intellectual disability (Bouck et al., 2017). The present study instead describes how UDL-based supports were used during students' thinking processes. To keep the claims proportionate to the evidence, three levels should be distinguished. What was directly observed is that the students completed number tasks more accurately and stayed engaged for longer when quantities were presented concretely and visually, and that their performance declined when these supports were withdrawn. What informants reported is that the

teacher, the GPK, the parents, and the students perceived visual and concrete supports as helpful for attention and understanding. What the researchers interpret, drawing on cognitive load theory (Sweller et al., 2019) and representation theory (Bruner, 1966), is that UDL supports appeared to act compensatorily by easing working memory demands, bridging concrete and symbolic representations, widening the ways in which students could express understanding, and sustaining engagement. This interpretation is plausible within the three cases but was not tested causally.

The contribution of this study therefore lies in offering an analytically grounded description of how the cognitive barriers of students with intellectual disabilities correspond to the supports provided through the three UDL principles. Rather than claiming a general pedagogical mechanism, the study proposes a working account that can be examined in larger and more varied samples: UDL may serve not only as an approach that increases access to learning but also as a design framework that supports mathematical thinking processes when support is matched to each student's cognitive profile. This perspective complements outcome-focused UDL research by drawing attention to the learning process.

To clarify the direction of the discussion, the findings for each research question are synthesized in Table 4 in terms of their meaning, the factors underlying their emergence, their relation to theory, their position relative to previous research, and their analytical implications for teaching mathematics to students with intellectual disabilities. This synthesis ensures that the discussion moves beyond a description of the findings to show how they are interpreted and situated within a broader scientific framework.

Table 4

Analytical Synthesis of the Discussion by Research Question

Research question	Meaning of findings	Why the findings emerged	Relation to theory	Position relative to previous research	Analytical implications
RQ1: Cognitive barriers experienced by students	Major barriers include limited working memory and attention, difficulty with abstraction, limited generalization, and reliance on concrete representations	The cognitive characteristics of students with intellectual disabilities make numerical information difficult to retain and transfer.	Consistent with cognitive perspectives on learning (Schneider & Stern, 2010; Sweller et al., 2019) and with studies on the mathematics learning of students with intellectual disabilities (Bouck et al., 2017; Spooner et al., 2019)	Strengthens previous findings but shows that barriers persist even when instruction is adaptive.	Interventions should go beyond drill; they require cognitive load management, repetition, and visual support.

Research question	Meaning of findings	Why the findings emerged	Relation to theory	Position relative to previous research	Analytical implications
RQ2: Role of UDL principles	UDL supports thinking processes through accessible representation, flexible expression, and sustained engagement.	Students need differentiated instruction because their barrier profiles and strengths differ.	Consistent with the UDL principles of representation, action and expression, and engagement (CAST, 2018)	Extends UDL research from a focus on learning outcomes to a focus on supporting mathematical thinking processes.	UDL should be understood as needs-based pedagogical design, not simply the use of multiple media.

Table 4 shows that the findings are interrelated and form a coherent picture: the cognitive barriers that students with intellectual disabilities experience in understanding number concepts cannot be separated from their need for concrete experiences, visual support, and flexible learning designs that respond to these barriers. Thus, the discussion indicates that visual media-assisted UDL not only facilitates access to learning but also serves as a pedagogical framework that allows number concepts to be understood through pathways of representation, expression, and engagement that are better suited to the learning characteristics of students with intellectual disabilities.

Overall, the results suggest that the understanding of number concepts among these students with intellectual disabilities developed through the interaction between their cognitive characteristics and the quality of the instructional support provided by the teacher. Although the cognitive barriers identified could not be eliminated, their impact appeared to be reduced through the systematic, flexible, and sustained implementation of UDL. Therefore, mathematics learning in inclusive education may benefit from positioning UDL as a pedagogical framework that gives each student equal learning opportunities according to their needs and thinking characteristics.

3.3 Limitations

This study has several limitations that should be considered in interpreting the results. First, it used an exploratory case study involving three students with intellectual disabilities in one inclusive school, so the findings describe the characteristics of these cases and are not intended for statistical generalization. Second, it focused only on number concepts and does not describe how visual media-assisted UDL works for mathematical content with a higher level of abstraction, such as algebra, geometry, or problem solving. Third, the study was conducted over a relatively short period, so changes in the students' thinking could not be observed longitudinally. Fourth, the data were collected and interpreted by researchers who were present in the classroom, so researcher subjectivity cannot be fully ruled out; although analytic memos, consensus coding, and discussion with the teacher and the GPK were used, no

formal inter-coder reliability index was calculated, and member checking with the students themselves was not feasible because of their communication abilities. Fifth, the presence of an observer may have influenced the behavior of the students and the teacher (observer reactivity). Sixth, all data came from a single school and one mathematics teacher, so the findings reflect that particular context. Seventh, because UDL was implemented together with specific visual media and the teacher's scaffolding, the study cannot separate the contribution of UDL as a framework from that of the media or of individual scaffolding; the improvements observed may partly reflect these components rather than UDL as a whole.

Nevertheless, the study sought to enhance the credibility of its findings through triangulation of methods and sources, including observations; interviews with the mathematics teacher, the GPK, parents, and students; and analysis of documentation and student worksheets (LKPD). The analysis based on the model of Miles et al. (2014) was documented through coding matrices and analytic memos to make the interpretation process transparent.

Future research should involve more participants with varied categories of intellectual disability and different educational levels, include several schools and teachers, and use independent coders and formal member-checking procedures where feasible. Designs such as mixed methods, single-case experimental designs, or design-based research could examine the separate and combined contributions of UDL principles, visual media, and teacher scaffolding, evaluate long-term effects, and develop more adaptive digital visual media for students with special needs.

4. Conclusion

This study aimed to identify the cognitive barriers experienced by students with intellectual disabilities in understanding number concepts and to explain how visual media-assisted UDL supported their thinking processes during mathematics learning. The results indicate that the students experienced four main cognitive barriers, namely (1) limited working memory and attention, (2) difficulty understanding abstract concepts, (3) limited generalization of concepts, and (4) strong reliance on concrete representations. These four barriers did not appear separately but were interrelated and influenced the process of forming an understanding of number concepts.

The findings also show that, in these three cases, the implementation of the UDL principles, namely multiple means of representation, multiple means of action and expression, and multiple means of engagement, gradually supported the students' thinking processes. Presenting concepts through visual media and concrete objects helped the students build connections between quantities and number symbols, while flexibility in ways of expressing understanding gave each student opportunities to demonstrate abilities according to their cognitive characteristics. Furthermore, active

engagement during learning was supported through varied activities, feedback, and gradual guidance.

The main contribution of this study lies in describing how cognitive barriers and UDL-based pedagogical support corresponded during number-concept learning. Unlike previous studies that generally focused on the effectiveness of visual media or on learning outcomes, this study suggests that UDL principles can act as compensatory support that helps reduce the impact of working memory limitations, facilitates the transition from concrete experiences to symbolic representations, and supports the thinking processes of students with intellectual disabilities. Given the small number of cases, this account should be regarded as a context-bound, analytically grounded proposition to be tested in further research rather than as a generalizable mechanism.

Practically, the results can serve as a reference for mathematics teachers, special guidance teachers (GPK), and inclusive schools in designing more adaptive learning that aligns with the cognitive characteristics of students with intellectual disabilities. The implementation of UDL with the aid of visual media can be considered an approach that supports more inclusive and meaningful mathematics learning and provides equal learning opportunities for all students. This study is expected to serve as an initial foundation for developing inclusive mathematics learning through the integration of UDL and visual media and to open opportunities for further research on learning designs that accommodate the diverse learning characteristics of students in inclusive schools.

Statements and Declarations

Funding:

Funding details were not specified in the available study documentation.

Competing Interests:

The authors declare no conflict of interest.

Ethics Statement:

Research permission was obtained from the school principal. The study reports parental or guardian consent and student assent, with participant names replaced by pseudonyms. Publication of identifiable photographs requires separate consent and appropriate de-identification.

Data Availability:

The study involves minors with intellectual disabilities, and any sharing of research data must protect participant confidentiality and comply with the scope of consent. Requests concerning de-identified supporting materials should be directed to the corresponding author.

Author Contributions:

Lutfiah: Conceptualization, Writing – original draft, Writing – review & editing,

Visualization. Sudirman: Methodology, Formal analysis, Writing – review & editing. Endang Wahyuningrum: Validation, Supervision.

Declaration of Generative AI Use:

Generative AI was used to assist with language editing and editorial restructuring during revision of this manuscript. The authors are responsible for verifying the revised text against the original research records, reviewing all interpretations, and approving the final manuscript.

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