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AR-Math: Augmented Reality–Based Assistive Learning for Enhancing Numeracy Skills Among Students with Intellectual Disabilities

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Abstract: Numerical ability is essential for all students, particularly for those with intellectual disabilities who often face challenges in understanding basic mathematical concepts. This study aims to develop AR-Math, an Augmented Reality (AR)-based learning media designed to improve basic numeracy skills through an inclusive and gender-responsive approach. The development process followed the ADDIE model, which includes five stages: Analysis, Design, Development, Implementation, and Evaluation. This study employed a quasi-experimental design with a non-equivalent control group design. In this design, there were two groups, namely the experimental class and the control class. The experimental class used AR-Math as the main learning medium, while the control class continued learning with conventional methods. Data were collected using multiple instruments, including validation sheets, practicality questionnaires, pretests and posttests, classroom observation sheets, interview guides, and documentation. The sample consisted of 20 eighth-grade students with mild to moderate intellectual disabilities at SKh YKDW 01 Tangerang, divided into two groups. The results showed that AR-Math met the criteria of validity, practicality, and effectiveness. The effectiveness test revealed a significant improvement in students' basic numeracy skills, as indicated by a n-gain score of 0.50 and categorized as medium. Beyond cognitive achievement, AR-Math enhanced student engagement, accessibility, and ease of use for students with special needs. A key finding pertains to inclusivity and gender responsiveness. Equal participation between male and female students was observed, as evidenced by comparable levels of interaction, motivation, and task completion during the learning process. This indicates that AR-Math not only strengthens basic numeracy skills but also provides fair opportunities for all learners. Thus, AR-Math can be considered a relevant and innovative tool for inclusive education, supporting both academic development and gender equity in classroom practice.

Keywords: assistive, numerical, learning, intellectual, disabilities, augmented reality.

▪ INTRODUCTION

Education is a fundamental right for every individual, including students with intellectual disabilities. Within the framework of inclusive education, all students are entitled to receive equal and meaningful educational services tailored to their individual needs and potential. However, in practice, students with intellectual disabilities still have to cope with numerous barriers to accessing effective learning, particularly in subjects that require logical and abstract thinking skills, such as mathematics (Aghasafari et al., 2025; Steffek, 2019).

Mathematics is a crucial subject as it relates to the basic numerical skills needed in everyday life. Unfortunately, students with intellectual disabilities often struggle to understand abstract mathematical concepts, including numbers, arithmetic operations, and relationships between numbers (Spooner et al., 2019). Limitations in cognitive function, attention, and short-term memory make learning numerical skills more complex

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and require a different approach than for students with normal abilities (Sola-Ozguc, 2021).

In fact, conventional classroom learning methods sometimes fail to accommodate the learning needs of students with intellectual disabilities. The lack of concrete examples in conventional learning hinders student interaction, leading to low learning outcomes, a loss of motivation, and limitations in numerical skills (Ahmed et al., 2025; Odunga et al., 2025). Learning innovation is urgently needed to address these challenges. One approach is through technological advancements in education (Erickson et al., 2015; Lynch et al., 2024; Mirza et al., 2025). In today's digital era, rapid technological developments present an opportunity for education to create engaging, interactive learning media that can be designed to adapt to the needs of students with intellectual disabilities. Augmented reality (AR) is a technology that shows particularly rapid potential (Sırakaya et al., 2020; Turan et al., 2021; Yenioglu et al., 2021).

Augmented Reality (AR) is a technology that can accurately combine the real world with the virtual world, making the learning process more lively and more contextual, like the one in everyday life (Rakhimzhanova et al., 2025). With the use of AR, students with intellectual disabilities can not only see but also actively interact with three-dimensional objects that appear realistically (Rakhimzhanova et al., 2025; Quintero et al., 2019; Mokmin et al., 2022). Three-dimensional objects can be manifestations of basic mathematical concepts (Jdaitawi et al., 2021; Khowaja et al., 2020). This can enable students with intellectual disabilities to learn in a real way, and the learning process is tailored to the needs and characteristics of students with intellectual disabilities (Klochko et al., 2020; Kryszewska, 2017; Ajitha et al., 2022). Several previous studies have found that the use of AR learning media helps increase learning motivation, material understanding, and student engagement among those with intellectual disabilities. The 3D forms produced by AR help students to understand the basic concepts more clearly. Nevertheless, the application of AR in special education is still very limited, especially in the numerical curriculum for students with intellectual disabilities. Recent studies indicate that the application of augmented reality (AR) in special education remains limited, with a primary focus on autism spectrum disorder, while its specific use for individuals with intellectual disabilities, including higher-order cognitive development and daily living skills, is rarely explored (Jiwon et al., 2025; Huaman-Romani et al., 2023).

A gender-sensitive learning method is also crucial for creating a welcoming classroom environment for everyone. Female students with special needs, in particular, often experience fewer opportunities to interact with learning media or technology-related tools, resulting in a lack of self-confidence and difficulties in mathematics lessons, which often leads them to consider mathematics a boring and difficult subject (Darwish et al., 2025). Female students with special needs, in particular, often experience fewer opportunities to interact, a gap that can be better understood through the lens of the Universal Design for Learning (UDL) framework, which emphasizes multiple means of engagement, representation, and expression; without which, such inclusive design from gender-specific barriers to participation and interaction are likely to persist (Sanches-Ferreira et al., 2019). This situation results in gender inequality in the learning process, so that learning media that are highly accessible, adaptive, and highly responsive to gender are urgently required. Therefore, learning media with a gender and social inclusion approach are urgently needed to meet the needs of students with intellectual disabilities (International Labour Office, 2013). The developed learning media can provide opportunities for students with intellectual disabilities that foster self-confidence and learning motivation when used, allowing the learning process to run optimally (Ayon et al., 2021; Ali et al., 2021; Altindağ Kumaş, 2024).

Comparatively, AR-Math occupies a strategic position among augmented reality applications for mathematics learning because it provides technical features that are adaptive to students with special needs, such as a simple interface, multimodality, and adjustable levels of difficulty. From a pedagogical perspective, AR-Math not only functions as a medium for visualizing abstract concepts but also integrates the principles of Universal Design for Learning (UDL), making learning more inclusive and relevant to functional skills in everyday life and representing an approach that is relatively rare among similar applications (Roski et al., 2024). The use of learning media in the digital technology era, such as AR-Math, has the potential to provide different types of learning compared to conventional methods in inclusive education environments (Álvarez-Marín et al., 2023; Asatryan et al., 2023; Cascales-Martínez et al., 2017). AR-Math learning media can provide a more engaging and easily understood learning experience tailored to the abilities and learning speeds of each student with intellectual disabilities.

The principle of universal design for learning (UDL) in AR-Math learning media can support the improvement of learning outcomes for students with intellectual disabilities (Al-Azawei et al., 2017; Karisa, 2023; Navas-Bonilla et al., 2025). This is directly proportional to modern education, which encourages students to be active in the classroom. AR-Math is expected to be more than just a tool to assist students with intellectual disabilities, but can also improve basic numerical skills. AR-Math was developed with various interesting features so that students with intellectual disabilities can be directly involved with the introduction of three-dimensional mathematical concepts, the use of color, sound, and animation, which can create a more interesting and enjoyable learning atmosphere (Akçayır et al., 2017: Checa-Domene et al., 2023; Chen et al., 2024). This is very important so that students with intellectual disabilities can pay attention and concentrate only on the AR-Math application without being distracted by other things (Intarapreecha et al., 2023; Fernández-Batanero et al., 2022).

The AR-Math development process involved teachers identifying the initial needs of students with intellectual disabilities so that the learning media developed were tailored to their needs and characteristics. Parents and students were also involved to ensure ease of use. To address this situation, AR-Math was developed, providing easier user access and a user guide. This was intended to assist parents to be directly involved in supporting their children's learning process at home and strengthening the learning environment for students with intellectual disabilities, both in school and outside of school. The implementation of AR-Math must be supported by both the school and teachers' readiness to implement it in the classroom. Hence, media development and media introduction to teachers should also be carried out to minimize obstacles to AR use in the school environment or in inclusive education.

It can be stated that AR-Math serves as a solution in educational technology for both mathematics learning and as a model for a special learning approach for children with intellectual disabilities, based on gender and social inclusion, to equalize educational opportunities for all students. This research is expected to serve as the initial impetus for media development research in other fields, creating a learning environment that is more appreciative of the diversity of student characteristics and ensures the right to learn for everyone, regardless of gender or disability. The development of learning media itself is expected to solve these problems, as evidenced by the existence of AR-Math learning media that utilizes augmented reality specifically designed for mathematics learning to enhance the basic numerical abilities of children with intellectual disabilities. In addition, AR-Math focuses not only on the technology being developed but also on the principles of gender and social inclusion, ensuring that all students can use the medium fairly and equally. AR-Math learning media is designed to be user-friendly and accessible. Additionally, it can be used without an access limit, allowing students and parents to use it at home, even without a teacher's presence. Moreover, AR-Math is designed in accordance with the needs of students with intellectual disabilities, regardless of gender; thus, anyone can access it without difficulty.

The purpose of this study is to develop and test the effectiveness of AR-Math learning media in improving the basic numerical skills of students with intellectual disabilities. The research also adopts a gender and social inclusion approach, ensuring that all students can participate, regardless of gender or ability, particularly in inclusive education settings. In other words, students with intellectual disabilities have opportunities to use appropriate learning media with technology as support. The results of this study are also expected to make a significant contribution to the development of educational technology that considers the needs of students with disabilities, regardless of their gender or abilities.

Through this research, it is expected that AR-Math will serve as a concrete example of the application of inclusive educational technology oriented towards the real needs of students. An approach that combines aspects of technology, disability, and gender will pave the way for more holistic and socially just educational innovation. Therefore, the development and implementation of AR-Math aims not only to improve mathematics learning achievement but also to strengthen the values of inclusion and equality within the education system. This underpins the importance of this research. In line with this objective, the research question posed in this study is: How can the development and implementation of AR-Math learning media effectively enhance the basic numerical skills of students with intellectual disabilities while simultaneously strengthening inclusive education practices in schools?

▪ METHOD

Participants

The subjects in the research and development of the AR-Math application were eighth-grade students of SKh YKDW 01 Tangerang. The research was conducted in two classes, namely the experimental class and the control class. Each class, namely VIIIA and VIIIB, consisted of 10 students, resulting in a total of 20 samples in this study. The research sample was selected using purposive sampling with the following criteria: junior high school students with intellectual disabilities, limited basic numerical skills, and the ability to participate in learning activities with the support of a teaching assistant. The students demonstrated varied initial cognitive abilities, ranging from basic number recognition to requiring full assistance in fundamental operations. Their prior experience with technology also differed, from having used simple digital devices to having little or no exposure. They generally required clear visual instructions, repetition, and multimodal support in the learning process.

Research Design and Procedures

AR-Math was developed as an assistive technology-based learning application for children with intellectual disabilities in mathematics learning to improve basic numerical skills such as number recognition, arithmetic operations, multiplication, and division (Alzahrani et al., 2025; Devi, 2019; Sahoo et al., 2025; Rizk et al., 2022)AR-Math was developed using a research and development (R&D) method, adopting the ADDIE development model, as shown in Figure 1, with five stages: Analysis, Design, Development, Implementation, and Evaluation. This study employed a quasi-experimental design with a non-equivalent control group design. There were two groups, namely the experimental class and the control class, which were not randomly assigned. The experimental class received instruction using the AR-Math learning media, while the control class continued with conventional teaching methods as regularly conducted by the teacher. A comparison between the two groups was carried out through pre-test and post-test measurements of basic numerical skills.

Figure 1. ADDIE stages

Analysis

The analysis stage encompasses identifying the initial needs of students with intellectual disabilities. Interviews are conducted with teachers regarding students with intellectual disabilities in the classroom, the availability of teaching materials, and the learning media currently used. The initial AR-Math design is also ensured to meet the needs of students with intellectual disabilities. The features in the AR-Math developed are tailored to the motor and sensory abilities of students with intellectual disabilities. The analysis stage is a crucial initial step, as it is the primary factor supporting the AR-Math development process.

Design

The design stage begins after the initial requirements have been identified during the analysis stage. A storyboard is used to determine the initial design and position the features used in AR-Math. This design is based on interviews with teachers of students with intellectual disabilities, and its features are aligned with the characteristics of these students. The augmented reality displayed on three-dimensional objects is designed to be engaging and easily understood by students with intellectual disabilities.

Development

In this stage, the AR-Math application is built on the previous stage. The entire AR-Math development process is tailored to the characteristics of students with intellectual disabilities, so the use of sound, color, content is specifically designed to meet their needs.

Implementation

The implementation phase involved introducing AR-Math in the school environment, specifically in classes for students with intellectual disabilities. Teachers are a crucial factor, as they are responsible for guiding students in using the AR-Math application. However, prior to student trials, teachers and experts were involved to ensure the application meets the needs of students with intellectual disabilities. The trials were conducted on a limited scale to assess the challenges of using AR-Math in the classroom to improve the numerical abilities of students with intellectual disabilities. The intervention was conducted over four weeks, with two sessions per week, each lasting approximately 40 minutes. During implementation, teachers followed a structured protocol that included (1) introducing the learning objectives, (2) facilitating the use of AR-Math during practice activities, and (3) providing feedback and reinforcement at the end of each session. To ensure treatment consistency, teachers were trained beforehand and provided with written guidelines that included step-by-step procedures, instructions for scaffolding students' learning, and strategies for managing classroom interactions. The trials were initially conducted on a limited scale to identify potential challenges in using AR-Math in the classroom. After refinement, full implementation was carried out to evaluate its effectiveness in improving the numerical skills of students with intellectual disabilities.

Evaluation

The final stage is evaluating the learning outcomes and the effectiveness of AR-Math as a learning tool. This involves assessing students' numerical abilities before and after using the app, as well as collecting feedback from teachers and parents. The results are used to inform further refinement, ensuring that AR-Math continues to meet the needs of children with intellectual disabilities and improve their numerical abilities.

Instrument

The data collection instruments in this study consisted of two main components. First, the validity of AR-Math in basic mathematical skills material (whole numbers, arithmetic operations, multiplication, and division) was assessed using two instruments: a media validity sheet, completed by media experts, with 10 items evaluating design, navigation, interactivity, readability, and appropriateness for students bearing intellectual disabilities (e.g., “The AR-Math interface is easy to understand for students with intellectual disabilities”), and a material validity sheet, completed by subject matter experts, with 10 items measuring content accuracy, curriculum alignment, systematic presentation, relevance to learning objectives, and level of difficulty (e.g., “The arithmetic operations material in AR-Math is aligned with the prescribed basic competencies”). Second, the effectiveness of AR-Math was evaluated through a student response questionnaire and a numerical skills test. The students' questionnaire consists of 10 items, covering learning satisfaction (e.g., “I enjoy learning mathematics using AR-Math”), self-confidence, perseverance/enthusiasm, and perceived ease of use, which were completed with teacher support after the sessions. Meanwhile, the numerical skills test, administered as a pre-test and a post-test, measured improvements in number recognition, simple addition and subtraction, basic multiplication, and simple division. Instrument testing was conducted using a pre-test and post-test, with indicators listed in Table 1.

Table 1. Effectiveness test indicators

No	Indicator
1	The usefulness of the application for learning outcomes
2	The suitability of content to special needs
3	The quality of interaction with the media
4	The ease of use

The indicators in Table 1 can be developed into questionnaire items that are understandable for students with intellectual disabilities with the assistance of a supporting teacher. With such support, the effectiveness indicators can be operationalized into more inclusive questions. The supporting teacher plays an important role in ensuring that students understand the meaning of each question. This role involves reading questions aloud clearly, simplifying the language to make it easier to understand, providing concrete examples relevant to students' daily experiences, and assisting them in selecting answers based on their own understanding and experiences. In this way, students can provide more accurate responses while minimizing potential barriers arising from limitations in language comprehension or understanding abstract concepts.

Data Analysis

This study aims to develop a valid, practical, and effective AR-Math application. The AR-Math application was analyzed for validity, practicality, and effectiveness. This testing was conducted by two mathematics teachers from SKh YKDW 01 Kota Tangerang and two mathematics lecturers. The validity criteria are shown in Table 2 (Ferawati et al., 2025).

Table 2. Validity criteria

No	Percentage	Criteria
1	90% - 100%	Very Valid
2	80% - 89%	Valid
3	60% - 79%	Valid Enough
4	0 – 59%	Not Valid

The data for the practicality analysis were taken from the implementation of learning activities provided by the experts. The activities of students with intellectual disabilities were observed during the learning process, with a focus on the use of the AR-Math application to enhance their numerical skills. After the scores were obtained, the final results were adjusted according to the criteria in Table 3.

Table 3. Practicality criteria

No.	Percentage	Criteria
1	90% - 100%	Very Practical
2	80% - 89%	Practical
3	60% - 79%	Practical Enough
4	0% - 59%	Not Practical

The practicality of the AR-Math application was evaluated by administering a student response questionnaire. The data from the students' responses were obtained from students with intellectual disabilities who filled out the questionnaire with the assistance of their teachers. The questionnaire consisted of 10 statements with indicators such as learning satisfaction, self-confidence, perseverance/enthusiasm, and perceptions regarding the ease of use of the AR-Math application. The assessments carried out by students were then divided by the maximum score and multiplied by 100%. The percentages obtained were adjusted in accordance with the criteria presented in Table 4.

Table 4. Students' responses criteria

No	Percentage	Criteria
1	90% - 100%	Very Good
2	80% - 89%	Good
3	60% - 79%	Good Enough
4	0% - 59%	Not Good

The effectiveness of the AR-Math application in improving the numerical abilities of students with intellectual disabilities was evaluated by obtaining pre-test and post-test scores given to students with intellectual disabilities. Pre-test results were used to determine the level of students' initial abilities before using the application. In contrast, post-test results illustrated the increase in abilities after the learning intervention with AR-Math. To measure the magnitude of the increase in learning outcomes more objectively, N-Gain analysis was used. The data analysis was not only carried out using significance tests, but also complemented with the calculation of effect size to determine the magnitude of the treatment's influence on students' learning outcomes. The effect size was calculated using Cohen's d to compare the mean scores of the two groups and n-gain to assess the improvement from pre-test to post-test. The interpretation of effect size values refers to the categories of small, medium, and large; thus, the research findings can be evaluated not only as statistically significant but also as practically meaningful. The calculation of the N-Gain score was carried out by comparing the difference between the pre-test and post-test scores to the maximum score that could be achieved. This calculation formula refers to the equation developed by Hake (Ferawati et al., 2025), so that the results of the analysis can indicate the effectiveness of learning in the low, medium, or high categories according to applicable criteria.

Table 5. N-Gain score criteria

No	N-Gain (g) Score	Criteria
1	$g > 0.7$	High
2	$0.3 \leq g \leq 0.7$	Medium
3	$g < 0.3$	Low

Qualitative Data Analysis for Inclusion Aspects

Qualitative data analysis for inclusion aspects in this study was conducted through interviews with students, teachers, and learning assistants regarding the use of AR-Math. The interviews focused on indicators of accessibility, participation, social interaction, and learning motivation. The collected data were then analyzed through the stages of data reduction, data display, and conclusion drawing to obtain a deeper understanding of the role of AR-Math in supporting inclusive learning.

▪ RESULT AND DISSCUSSION

The Development of AR-Math

Analysis

Analysis is the initial stage, and interviews were conducted with mathematics teachers VIII SKh YKDW 01 Tangerang City to identify the basic needs of students with intellectual disabilities. The difficulties faced by students with intellectual disabilities include understanding basic numerical concepts, such as recognizing numbers, performing simple arithmetic operations, including addition, subtraction, multiplication, and division. This was done to ensure that the AR-Math application meets the needs of students. In the analysis stage, the researcher interviewed a mathematics teacher at SKh YKDW 01 Tangerang to identify the needs of students with intellectual disabilities in learning mathematics. This interview aimed to explore information regarding the difficulties faced by students, the learning media commonly used, and the potential use of technology-based media. The following is a direct excerpt from the interview between the researcher and the teacher:

Researcher : *"In your opinion, which part of mathematics is the most difficult to understand for students with intellectual disabilities?"*

Teacher : *"They usually struggle with basic arithmetic operations, especially when they have to combine addition and subtraction in one problem. In addition, the concept of place value is still confusing."*

Researcher : *"What learning media have you used so far in teaching mathematics?"*

Teacher : *"We usually use textbooks and the whiteboard. Sometimes we use simple teaching aids such as coins or ice cream sticks. But those are limited, and the students get bored quickly."*

Researcher : *"In your opinion, how would students respond if technology-based media is used, such as augmented reality?"*

Teacher : *"I think it could attract their attention. Children can focus more easily if there are moving visuals they can interact with. But of course, they still need guidance so that it is not merely playing without purpose."*

The interview suggests that students with intellectual disabilities continue to face challenges in understanding basic mathematical concepts, as conventional learning media are often ineffective in maintaining their attention and motivation. Therefore, the teacher considers the use of technology-based media such as augmented reality to have the potential to provide a more engaging learning experience, although it still requires intensive guidance.

Design

After the interviews were conducted during the analysis phase, the next stage was the design phase. The initial design phase is explained through a storyboard. The AR-Math application was developed using Universal Design for Learning (UDL) to accommodate the diverse abilities of students with intellectual disabilities. The design is illustrated in Figure 2. This serves as an initial design for positioning the features in the AR-Math application. These features have been adapted to the characteristics and abilities of students interacting with the AR-Math application.

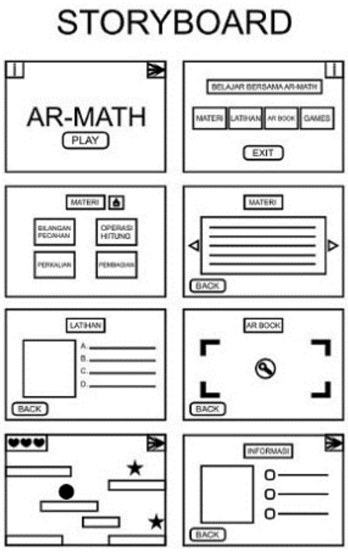


Figure 2. AR-Math storyboard

Figure 2 shows the AR-Math application flow, which includes the initial interface and a user guide designed for users such as teachers, parents, and students with intellectual disabilities. The design involved teachers and media experts who provided suggestions for the AR-Math application's content. This enabled the development of a prototype design in the next stage.

Development

During the development phase, the initial AR-Math design was transformed into an augmented reality-based application. The development process began with the creation of three-dimensional visual content, audio narration, and digital interactions that support basic numerical understanding for children with intellectual disabilities. The application was built using AR-supporting software, such as Unity 3D and the Vuforia SDK, enabling it to interactively display virtual objects when students scan the provided markers or cards. Internal testing was conducted in stages to ensure that all features functioned properly, including menu navigation, AR displays, and automatic feedback.

Figure 3. Initial display and ar-math home menu

Figure 3 refers to the homepage of an educational app called AR-MATH, designed for Augmented Reality (AR)-based math learning. This interface features a cheerful visual design with bright colors and illustrations of children surrounded by numbers, providing a fun and welcoming experience for students with intellectual disabilities.

This phase tests the feasibility of the AR-Math application. Validation is conducted to measure the feasibility of the AR-Math application. This process is carried out by four validators consisting of two mathematics teachers from SKh YKDW 01 Tangerang and two lecturers from the informatics engineering study program with mathematics expertise. The feedback provided by these experts serves as an important reference to ensure the application meets the primary standards regarding ease of use, functionality, and educational value, thereby enabling its proper implementation as a learning tool. The expert assessment of the aspects of display/visual design, interactivity, technical quality, and instructional relevance was conducted using a questionnaire instrument with a 5-point Likert scale, ranging from 1 (strongly inappropriate) to 5 (strongly appropriate). The expert assessment was conducted using a questionnaire instrument with a 5-point Likert scale, ranging from 1 (strongly inappropriate) to 5 (strongly appropriate). The scores provided by the validators were then converted into normalized average scores within the range of 0–1 and subsequently expressed as percentages to facilitate interpretation and understanding. The validity category was determined based on specific criteria, where a score of 0.80 or higher was categorized as valid.

Table 6. Expert assessment results

No	Assessment Aspect	Score				Percentage	Category
		V1	V2	V3	V4		
1	Display/Visual Design	0.85	0.86	0.85	0.91	87%	Valid
2	Interactivity	0.86	0.84	0.85	0.82	84%	Valid
3	Technical Quality	0.91	0.89	0.85	0.86	88%	Valid
4	Instructional Relevance	0.88	0.91	0.88	0.89	89%	Valid
	Average	0.88	0.82	0.88	0.86	87%	Valid

Based on the above results, the Display/Visual Design aspect received a score of 87%, categorized as valid. This indicates that AR-Math's visual display is both attractive and easy to understand, supporting students in using the application effectively. The selection of colors, layout, and visual elements was deemed appropriate for learning needs. The Interactivity aspect received a score of 84%, categorized as valid. Although considered quite good, this aspect ranked lowest compared to the others. The experts' feedback suggested that AR-Math could benefit from more diverse interactive features, such as immediate feedback, dynamic animations, and progressively challenging tasks, to better engage students. These insights suggest that future development should prioritize enhancing interactivity to ensure that students with diverse learning needs can actively engage in exploring mathematical concepts, thereby making AR-Math more effective, inclusive, and student-centered.

In the Technical Quality aspect, the AR-Math application received a score of 88%, categorized as valid. The application was deemed stable, the augmented reality feature was usable, and it was compatible with existing devices. This demonstrates that AR-Math's technical quality is adequate to support the learning process. The highest score was 89% in the instructional relevance aspect, with a valid category. This aspect indicates that AR-Math aligns with the existing curriculum at SKh YKDW 01 Tangerang. Therefore, the material or content aligns with the learning objectives, and the material presented in the application effectively supports students' ability to understand the material well. The average validator assessment aspect obtained 87% in the valid category. This suggests that the AR-Math application can be considered a suitable learning medium to enhance the basic numerical of students with intellectual disabilities.

It can be stated that the feasibility assessment results were declared valid, followed by an assessment of the practicality of the AR-Math learning media. After conducting the validity test, the next step was to assess the practicality aspect. This practicality aspect was used to assess the AR-Math application during the learning process, ensuring it was easy for teachers and students to use without experiencing complex obstacles. The practicality assessment was carried out using indicators such as time efficiency, instructional support, and student engagement. This assessment was conducted to measure the time efficiency when using the application, the learning media that support the learning process, and the ability to engage students with intellectual disabilities. The practicality assessment conducted by four assessors during the learning activities is presented in Table 7.

Table 7. Practicality assessment results

No	Assessment Aspect	Score				Percentage	Category
		V1	V2	V3	V4		
1	Time Efficiency	0.84	0.87	0.89	0.91	88%	Pratical
2	Instructional Support	0.89	0.85	0.88	0.82	86%	Pratical
3	Student Engagement	0.92	0.85	0.89	0.92	90%	Pratical
	Average	0.91	0.86	0.89	0.90	89%	Pratical

According to Table 7, the assessment results indicate a time efficiency of 88% in the practical category. These results indicate that AR-Math, used by students with intellectual disabilities, is very efficient, as evidenced by the learning time without requiring additional class hours. In the second aspect, namely instructional support, the score gained was 86%. This demonstrates that AR-Math is highly beneficial for both teachers and students in learning basic numerical skills, and the application's material has been tailored to accommodate students with intellectual disabilities. As for the third aspect, student engagement bears a score of 90%, the highest score of the three assessment aspects. AR-Math can, therefore, be one of the factors that encourages students with intellectual disabilities to be more motivated to learn, allowing them to be actively involved in learning activities. The overall average practicality assessment of the AR-Math application was 89% in the practical category. It can be concluded that the AR-Math application serves as an effective learning medium for understanding basic numerical skills among students with intellectual disabilities, and is highly practical in supporting learning activities in the classroom.

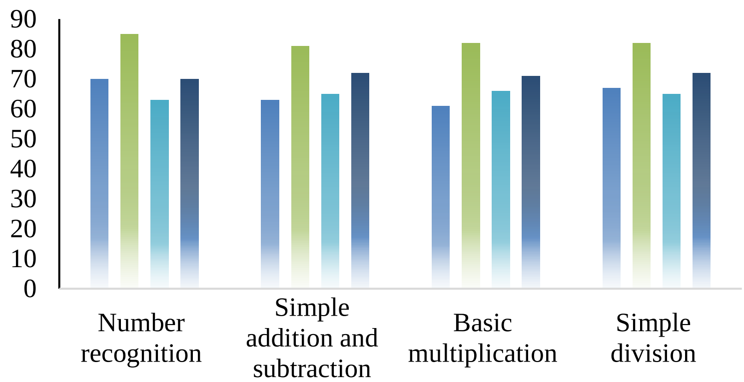
Implementation

After the development phase was completed, the implementation phase was carried out. At this stage, the AR-Math application was tested through three consecutive learning sessions conducted in a classroom setting with the students. The trial aimed to observe how students interacted with the application, the extent to which they could follow the learning, and whether the features provided supported their understanding of the material.

Figure 4. The use of the ar-math application

Figure 4 illustrates the use of the AR-Math application during the learning process with simple materials, namely number recognition and arithmetic operations. Throughout the sessions, the teacher guided the students to ensure that the application was used properly and that the learning process ran smoothly.

The effectiveness of the AR-Math application was evaluated by comparing the N-Gain scores for each indicator of AR-Math application usage in basic mathematics skills materials, using pre-tests and post-tests conducted with students. The pre-test was given to students before they received basic mathematics skills learning treatment without using the AR-Math application. After the development product was implemented in the learning environment, students' basic mathematics skills were assessed using a post-test. The results of the pre-test and post-test were assessed by reviewing each indicator and analyzing the N-Gain score for each indicator of AR-Math application usage in basic mathematics skills material. It can be stated that the application of learning with the AR-Math application in basic mathematics skills material provided positive improvements for each student with special needs.



	Number recognition	Simple addition and subtraction	Basic multiplication	Simple division
Experimental Pretest	70	63	61	67
Experimental Postest	85	81	82	82
Control Pretest	63	65	66	65
Control Postest	70	72	71	72

Figure 5. Pretest–Posttest comparison of experimental and control groups

Based on Figure 5, it can be seen that both the experimental and control classes experienced an increase in average scores from the pretest to the posttest for each numerical indicator. In the experimental class using AR-Math, a significant improvement was observed in all indicators. For example, number recognition increased from 70 to 85, and basic multiplication improved from 61 to 82. Meanwhile, the control class also showed an increase, although relatively smaller, such as in simple addition and subtraction from 65 to 72. These results indicate that the use of AR-Math in the experimental class was more effective in improving students' numerical abilities compared to the conventional method in the control class.

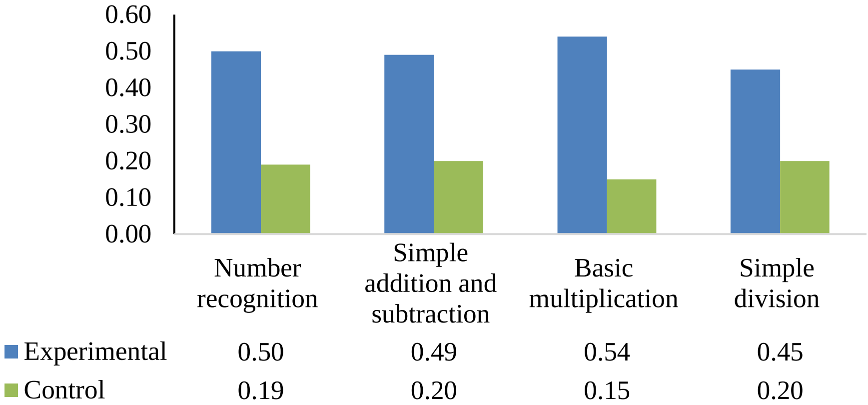


Figure 6. N-Gain comparison of experimental and control groups

Based on Figures 5 and 6, the number recognition indicator shows that students' scores increased from 70.00 in the pretest to 85.00 in the posttest, with an n-gain of 0.50. This suggests that AR-Math successfully enhanced students' accuracy and confidence in recognizing numerical symbols, which is a fundamental prerequisite for subsequent mathematical skills. This application helps simplify abstract concepts into more concrete ones through AR visualizations, making it easier for students to absorb the material. A study by Jang et al (2021) It was also confirmed that augmented reality helps improve learning outcomes by facilitating the understanding of complex concepts. From a gender and social inclusion perspective, this application is considered beneficial for both male students, who are generally more interested in technology, and female students, who face barriers in accessing digital learning media. Thus, AR-Math plays a significant role in creating more equal learning opportunities. These findings align with the APOS (Action, Process, Object, Schema) theory in mathematics education, which emphasizes the importance of mental structures in comprehending mathematical concepts deeply. The flexible implementation of UDL allows students to progress through the APOS stages according to their individual needs and abilities (Borji et al., 2018).

The simple addition and subtraction indicator rose from 63.00 to 81.00, resulting in an n-gain of 0.49. This moderate improvement reflects students' growing ability to perform basic arithmetic operations with greater accuracy and fluency. The results indicate that AR-Math's interactive features provided effective scaffolding, supporting students in practicing routine calculations and thereby reducing common errors and improving learning motivation. This research is supported by Aghasafari et al. (2025) &

Steffek (2019), who found that learning media using technological developments specifically designed for children with intellectual disabilities can increase their engagement and understanding during both in-class and out-of-class learning. In addition, in terms of gender and social inclusion, AR-Math provides an inclusive learning space that accommodates students' diverse backgrounds, regardless of their gender or disability conditions. This strongly supports the principle of inclusive education, prioritizing equal access to learning for every student. This approach aligns with Constructivist theory, which emphasizes the active role of students in building knowledge through experience and social interaction (Bada, 2015).

The highest improvement was observed in the basic multiplication indicator, which increased from 61.00 to 82.00 with an n-gain of 0.54. This finding highlights that AR-Math was particularly effective in helping students master multiplication, which is often considered more complex than addition or subtraction. The higher gain suggests that the visual and interactive representations offered by AR-Math facilitated conceptual understanding of repeated addition, making multiplication more accessible to students with intellectual disabilities. This is supported by Filiz et al., (2023) stating that interactivity or interaction is one of the important factors in the learning process, so that the AR-Math application can create interactions during the learning process (Cascales-Martínez, 2023). Meanwhile, in terms of gender and social inclusion. This application provides a learning experience that is acceptable to the learning environment and all students, regardless of gender (Hashim et al., 2024; Huaman-Romani et al., 2023).

Meanwhile, the simple division indicator improved from 67.00 to 82.00, with the lowest n-gain of 0.45. Although the learning gain was moderate, this result indicates that division remains a relatively challenging concept for students compared to other basic operations. Nevertheless, the improvement still reflects the positive role of AR-Math in supporting students’ comprehension of division, even though additional practice and reinforcement may be required to strengthen mastery in this area. This is supported by Akçayır & Akçayır (2017), who explain that users' perceived ease of use influences the success of AR implementation in education. In terms of gender and social inclusion, the application's ease of use ensures that both male and female students can use it with minimal technical barriers. Thus, it can be stated that this supports the creation of a friendly, inclusive, and fair learning environment for all students. Overall, these findings indicate that the use of AR-Math effectively enhanced students’ basic numerical skills, with an average n-gain of 0.50, categorized as medium.

Based on figure 7 shows the distribution of students with mild and moderate learning disabilities across four domains of mathematical ability before and after learning with AR-Math. In general, the percentage of students in the mild category increased after the intervention, for example, in the simple division domain from 58% to 78%, basic multiplication from 50% to 70%, simple addition and subtraction from 55% to 75%, and number recognition from 60% to 80%. Conversely, the percentage of students in the moderate category decreased in all domains, such as simple division, from 42% to 22%, and basic multiplication, from 50% to 30%. These results indicate that the use of AR-Math was able to shift more students from the moderate to the mild category, resulting in an overall improvement in mathematical ability among students with intellectual disabilities.

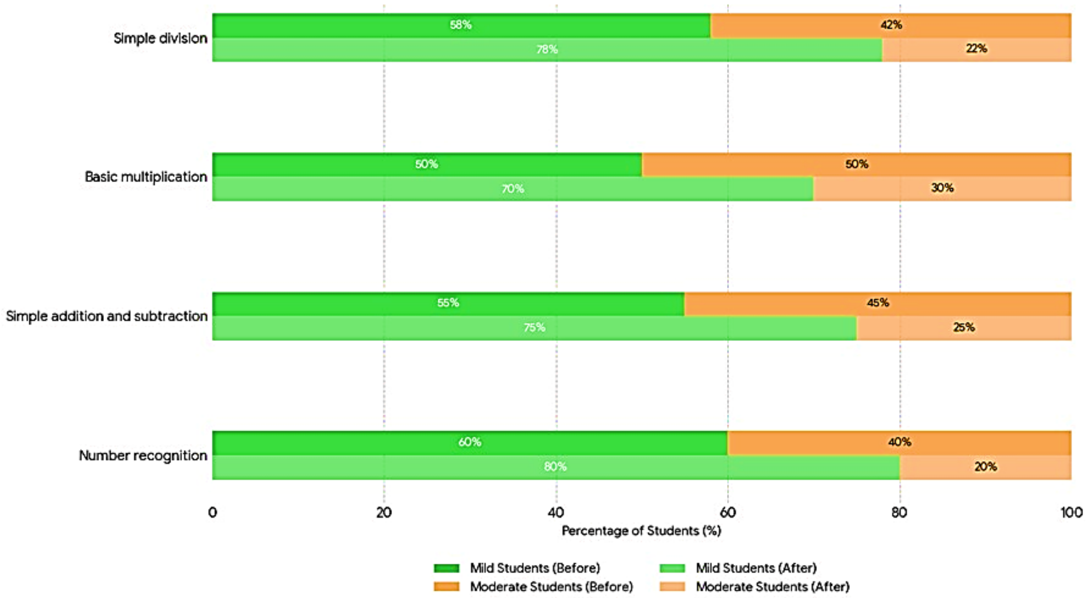


Figure 7. Distribution of student categories before and after the use of ar-math

Observation on Students' Use of AR-Math

The observation results of students' use of AR-Math, with particular attention to the level of participation between male and female students. The observed activities were classified into two categories: operating the AR-Math application and solving problems in AR-Math. The findings indicate that both male and female students demonstrated active and balanced participation during the learning process with AR-Math, as shown in Table 10.

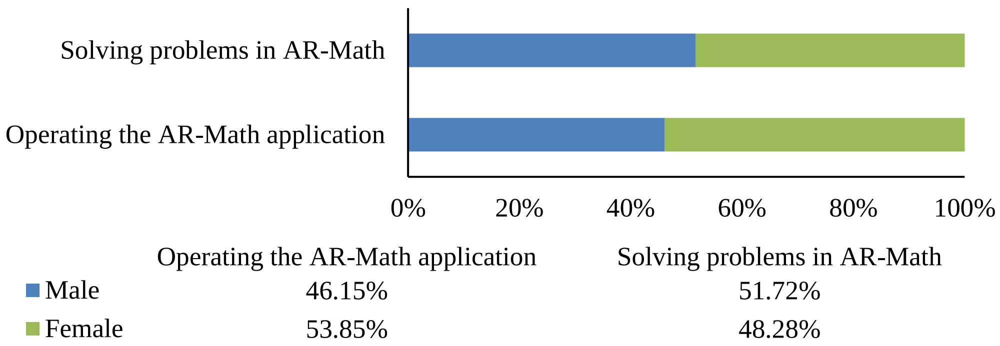


Figure 8. Frequency of student activities by gender in the use of ar-math

The observation results presented in Figure 8 show that both male and female students were actively engaged in using AR-Math. Male students recorded a total of 27 activities, while female students recorded 28 activities. In the category of operating the AR-Math application, male students accounted for 46.15% of the activities, while female students contributed 53.85%. Meanwhile, in solving problems with AR-Math, male students represented 51.72% of the activities, compared to 48.28% for female students. These findings indicate that the distribution of participation was relatively balanced, suggesting that the use of AR-Math provided equal opportunities for both male and female students to actively participate in the learning process.

Evaluation

The final stage of ADDIE was the evaluation stage, conducted to assess students' responses to the AR-Math application that had been implemented in the classroom. The evaluation was conducted on 10 mentally retarded students in grade VIII at SKh YKDW 01 Tangerang. Previously, the students had completed a trial for three learning sessions, and then they were given a questionnaire. During the completion of the questionnaire, the students were assisted by a teacher. The evaluation was conducted after the implementation of the AR-Math application in basic numeracy learning. The instrument used was a student response questionnaire, facilitated by the teacher, to ensure that each statement could be well-understood. The questionnaire was structured in the form of simple sentences with straightforward answer options, allowing the results to represent the students' learning experience accurately. The indicators used in the evaluation included learning satisfaction, which is the extent to which students felt happy and satisfied after participating in learning using AR-Math; self-confidence, an increase in students' confidence towards the understanding and working ability on basic numeracy problems through the help of the application; perseverance/enthusiasm, which describes students' consistency and enthusiasm in completing learning activities; and perceived ease, which is students' assessment of the level of easy accessing, understanding, and using the AR-Math application during the learning process. The results of the students' responses in the questionnaire served as the basis for evaluating the effectiveness of the AR-Math application. This supports the basic numeracy learning, especially for children with intellectual disabilities.

Table 8. Students' responses assessment results

No	Assessment Aspects	Percentage	Category
1	Learning Satisfaction	88%	Good
2	Confidence	86%	Good
3	Enthusiasm	85%	Good
4	Ease of Use	87%	Good
	Average	86.5%	Good

The results of the assessment of students with intellectual disabilities' responses to the use of the AR-Math application showed an average score of 86.5%, indicating a good category. The learning satisfaction aspect obtained the highest score of 88%, indicating that students feel happy and satisfied with using the application. Additionally, the aspect of perceived ease of use was also high at 87%, indicating that AR-Math is considered easy to understand and operate by students. Other aspects, such as self-confidence (86%) and perseverance/enthusiasm (85%), are also in the good category, indicating that this application can help increase students' self-confidence and encourage them to be more diligent in the learning process. Overall, these results suggest that AR-Math is an effective and practical tool for use as a learning medium to help students with intellectual disabilities understand basic multiplication concepts in a more engaging way.

Limitations of the Research and Practical Implications

This study has several limitations that need to be acknowledged. First, the sample size was relatively small and focused on only one school, which limits the generalizability of the findings to different educational contexts. Second, the research only assessed the short-term impact of AR-Math and thus has not provided insights into its long-term effects on student learning outcomes and aspects of inclusion. Third, technical constraints such as the availability of compatible devices and stable internet access remained challenges in the implementation of AR-Math in the field. The findings of this study offer practical implications that can be applied in educational practice. Teachers can utilize AR-Math as a supplementary tool in mathematics learning to enhance motivation and the understanding of basic concepts, particularly for students with special needs. Schools are encouraged to provide training for teachers and learning facilitators to optimize the use of AR-Math in accordance with the principles of inclusive education. In addition, education policymakers may consider integrating AR-Math into digital learning programs in schools, thereby ensuring equal access to learning opportunities for all students, including those with intellectual disabilities.

▪ CONCLUSION

The findings of this study indicate that the implementation of AR-Math has a significant positive impact on four main indicators: improvements in learning outcomes, the suitability of content for students with intellectual disabilities, the quality of interaction with the learning media, and users' comfort in using the application. The increase in scores from pre-test to post-test across these indicators confirms that AR-Math is not only effective in enhancing the understanding of basic numerical concepts but also provides a more meaningful and inclusive learning experience for children with special needs. These findings support previous studies that have shown augmented reality can enhance students' motivation, interactivity, and accessibility to learning media. Thus, the research objective has been achieved by demonstrating the role of AR-Math as an innovative learning medium that promotes inclusive, equitable, and student-friendly education.

The implications of this study highlight the potential of AR-Math as an alternative learning medium to strengthen inclusive education practices in schools, particularly in supporting the participation of students with intellectual disabilities. However, this study has certain limitations, including a relatively small sample size and a focus on only basic numerical concepts, which restricts the generalizability of the findings to other subjects or broader learning contexts. Future research should therefore involve more diverse samples and extend the scope of learning materials to test the effectiveness of AR-Math in wider educational contexts. Based on these limitations, further studies are encouraged to develop AR-Math more comprehensively so that it can optimally contribute to the advancement of truly inclusive and sustainable education.

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