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Augmented Reality Game-Based Learning: Enhancing Basic Mathematics Abilities for Students with Special Needs

Ferawati[1,*], Fiqih Hana Saputri[1], Lilis Stianingsih[1], Eka Uliyanti Putri[1], Detin Sofia[1], & Muhammad Iqbal Hanafri[2]

[1]Departement of Information and Communication Technology, Institut Teknologi dan Bisnis Bina Sarana Global, Indonesia

[2]Departement of Graduate Institute of Digital Learning and Education, National Taiwan University of Science and Technology, Taiwan

Abstract: Basic math skills are very important not only for students in general, but also for those with special needs. Students can learn math in a fun way through an engaging learning medium, one of which is augmented reality game-based learning can help students face challenges in understanding basic math concepts. This research aims to develop valid, practical and effective augmented reality learning media applications. The type of research applied is research and development (R & D) with the development of 4D models. The Data collection techniques and instruments include validation sheets, practicality sheets, tests, observations, interviews, questionnaires and documentation. The research sample encompasses 12 students sitting in grade 5 at SKh YKDW 01 Tangerang. The results of the research show that : (1) The validity of the augmented reality learning application meets the very valid criteria. (2) The augmented reality learning application is found to be very practical. (3) The results of product effectiveness analysis were obtained from test results and student responses in questionnaire sheets N-Gain score bearing 0.84 in the high category with indicators: the utilizing and understanding application devices, the ease of access and use, the students engagement and motivation, and the supporting collaborative learning. Additionally, these affirm that the AR is very effective in increasing the engagement, understanding, and math skills of children with special needs. Therefore, the designed augmented reality learning media are suitable for improving the basic mathematical abilities of children with special needs.

Keywords: math, AR, student special need.

▪ INTRODUCTION

Today Educators face the challenges of catering to an increasingly diverse students population, many of whom have complex academic and emotional needs. One particular need is a group of students with special needs who should face challenges in accessing the same learning materials with their classmates. They struggle to understand and participate in class discussions without adequate tools. Tools such as educational software (for example, apps for students with dyslexia), symbol-based communication (for students with speech impairments), or vision devices (for students with visual impairments) can help make learning more inclusive and accessible. Providing effective support for students with special needs in the classroom is an urgent concern in the education system (Feldman, 2017). In today's digital era, integrating technology into the learning process has become essential. One effective approach is the use of augmented reality (AR) in game-based learning. Augmented reality is a technology that blends virtual components with the physical world, offering users an enriched and interactive experience (Annafi et al., 2019).

Ferawati
*Email: ferawati@global.ac.id

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As digital transformation continues, the use of technologies and devices in education is becoming more widespread. One significant technological development is augmented reality, which is being increasingly applied in the fields of science and engineering education. Augmented reality is highly motivating, as it can enhance students' engagement and interest in activities. Moreover, it can offer valuable support to students with special educational needs (Fernández-Batanero, 2022). Previous research by Bhushan (2024) PISA (Program for International Student Assessment) reported that students with special needs often experience significant achievement gaps in mathematics if compared to regular students. In OECD countries, children with disabilities score lower on mathematics tests than children without disabilities, with gaps reaching more than 50 points in average scores. This emphasizes the importance of exploring innovative educational approaches, such as the use of AR, to support the learning of students with special needs and address these achievement gaps.

In recent years, the field of educational technology has seen significant innovations, especially in the areas of immersive augmented reality and game-based learning methods (Alper, Öztas, Atun, Çinar, & Moyenga, 2021; Yu, Denham, & Searight, 2022). These technological advancements have revolutionized traditional educational methods by providing engaging and interactive learning experiences (Blaschke, 2021). Incorporating technology into education enables the simulation of concepts, interaction with subject-matter experts, enrichment of existing resources, and the introduction of real-world challenges into the classroom, all of which have been shown to enhance students' learning and engagement (Bacca et al., 2014).

Scholarly research has further validated these assertions, demonstrating that the use of ICT in education can enhance teaching methods, supplement learning resources, and boost both teaching effectiveness and student learning outcomes (Arhin et al., 2024; Hsieh & Maritz, 2023; Radovan & Radovan, 2023). Earlier applications of augmented reality have demonstrated notable improvements in learning outcomes across various academic disciplines and education levels (Pathania et al., 2023).

The growing development and research of AR applications aimed at teaching various scientific subjects (Gong et al., 2021; Yoke et al., 2019; Bistaman et al., 2018; Kesim & Özarslan, 2012). This is supported by evidence showing that when augmented reality is integrated with pedagogical and psychological principles, students can enjoy an engaging and immersive learning experience. Within the context of game-based learning, augmented reality has shown promising potential in the field of education (Cai et al., 2021).

This technology shows great potential as a tool to improve the learning outcomes of students with special needs, particularly in the area of basic mathematics. Specifically, multimedia-based augmented reality games have yielded promising results in boosting students' proficiency in essential mathematical concepts, one of which is memorizing multiplication tables (Rebollo et al., 2021). For children with special needs, these games can increase the effectiveness and engagement of repetitious tasks by incorporating interactive and visually appealing components (Rebollo et al., 2021). Additionally, the "presence" that augmented reality produces can improve the learning environment even more by enabling students to get fully engaged with the mathematical problems being given to them. (Pamungkas, 2020; Cai et al., 2021; Jdaitawi et al., 2022; Rebollo et al., 2021).

For students to succeed both in academic and everyday life, it is essential for them to master basic mathematical skills such as addition, subtraction, multiplication, division, and number sense (Corso et al., 2024). These skills lay the foundation for more advanced mathematical concepts and problem-solving strategies, which significantly impact educational and career opportunities. However, the 2023 Sustainable Development Goals Report predicts that by 2030, 300 million students will lack basic literacy and numeracy skills, suggesting that progress toward ensuring quality education has been slower than expected (May et al., 2024).

Hence, augmented reality game-based learning can offer significant advantages in teaching fundamental math skills to children with special needs. These students often face unique challenges in grasping basic mathematical concepts, and traditional teaching methods may not fully address their individual learning needs. However, augmented reality games provide a more engaging and multi-modal approach, which can be better tailored to accommodate diverse learning styles and skill levels (Lutz, 2023).

Research has shown the positive impact of augmented reality games on student learning outcomes. These interactive experiences have been proven to enhance students' motivation, engagement, and understanding of mathematical concepts. Furthermore, the contextual and real-time interactivity of augmented reality helps children with special needs connect mathematical ideas to their daily lives, fostering the development of their problem-solving and self-regulation skills.

The existing literature suggests that augmented reality holds significant potential for enhancing children's foundational mathematical skills, although its use in special education is still in the early stages. As technology continues to evolve, integrating augmented reality into game-based learning environments can serve as a powerful tool for supporting the academic growth of children with various learning challenges. With the new opportunities it presents, augmented reality has emerged as a promising technology in education, particularly in improving the learning experience for students with special needs (Pamungkas, 2020).

Furthermore, it has been found that augmented reality in the classroom boosts student enthusiasm and engagement (Gaol & Prasolova-Førland, 2021). Research has also demonstrated that augmented reality, by providing a more immersive and personalized learning environment, can assist students with disabilities in their learning process (Jdaitawi et al., 2022)(Gaol & Prasolova-Førland, 2021). Additionally, it has been shown that game-based learning is effective for teaching students with special needs, as it makes the learning process more enjoyable and engaging (Aprinaldi et al., 2019) (Gaol & Prasolova-Førland, 2021). For this purpose, Augmented Reality applications can help learning activities take place in a fun way so that students are more interested in learning.

This research aims to develop an augmented reality learning media application for mathematics, designed to help students enhance their foundational skills and expand their knowledge through the dynamic features and real-time 3D visuals offered by the application. AR learning applications will impact how students learn and interact with mathematics learning material. This technology not only improves understanding of abstract concepts but also provides a more fun, interactive, and inclusive experience. With the ability to adapt learning to individual needs, AR has great potential to improve the quality of education, facilitate more personalized learning, and provide broader access to students with various needs, including those with special needs.

▪ METHOD

Participants

The test subjects of the research and development augmented reality application include students from grade V at SKh YKDW 01 Tangerang. The implementation was carried out in two classes, an experimental class and a control class, where each class, 5A and 5B consists of 6 students, so that the total sample was 12 students. The sampling technique used in this study was simple random sampling.

The sample size of 12 students may be limited in terms of representing a larger population, but it is sufficient for the purposes of this exploratory study. This research aims to identify patterns and dynamics in the use of AR applications to support students with special needs, as well as to provide initial insights that can serve as a foundation for further research with a larger and more diverse sample.

Research Design and Procedures

The augmented reality application designed for teaching basic mathematics, specifically aimed at children with special needs, was developed using the research and development (R&D) method. The augmented reality applications are created using the 4D development model (Ferawati, 2022), which encompasses four stages: define, design, develop, and disseminate.

Define

In this stage, interviews were conducted with mathematics teachers regarding the content currently problematic for classroom teachers. The selected mathematics learning content focuses on multiplication. The define stage also focused on creating educational game designs. Here, storyboards play a crucial role in multimedia development, particularly in the early stages of the design phase

Design

The design stage follows the define stage and serves as a foundation for developing the AR application. In this stage, the application is specifically designed to meet the needs and characteristics of children with special needs.

Develop

This stage is carried out after designing and developing the AR application for mathematics learning. The developers tested the application with two lecturers and two mathematics teachers and made necessary improvements.

Disseminate

In this stage, the developed product is distributed to students, and its effectiveness and impact are tested.

Instrument

The data collection instruments in this study consisted of (a) Validity of augmented reality application on the multiplication material assessed using the following instruments: (1) media expert validity sheet with 14 items regarding the validity of learning media; (2) material expert validity sheet with 15 items regarding the validity of material in the media. (b) The effectiveness of using the augmented reality mathematics

learning application with multiplication material was assessed through student response questionnaires. (1) Data on student responses were collected by having students fill out questionnaires, with assistance from teachers, after using the augmented reality application. The questionnaire includes 15 items designed to assess students' motivation, interest, and feedback on using the augmented reality application for learning multiplication. (2) Instrument tests are conducted through pre-test and post-test with indicators: utilizing and understanding application devices, ease of access and use, student engagement and motivation, and support collaborative learning.

Data Analysis

This research aims to develop augmented reality learning media applications that are valid, practical, and effective. The analysis of the validity, practicality, and effectiveness of the augmented reality learning media applications was conducted through various studies, including the validation of other products, the practicality of the product when used in learning, and the analysis of student responses to its use. The validity analysis involves calculating the average total validation score from four validators: two lecturers and two teachers. The product's validity is determined by comparing the validation score from the experts to the maximum possible score. The results of these calculations are then evaluated against predefined criteria on a specific scale to assess the validity level of the augmented reality learning media application. The validity criteria are presented in Table 1 below (Vela, 2021).

Table 1. Validity criteria

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

The practicality analysis is based on assessments of the learning implementation, which were provided by experts. Four experts evaluated the implementation of each learning step using the augmented reality mathematics learning application, focusing on multiplication material. Students activities during the learning process with the augmented reality application are the primary focus of the observations made by the experts. The practicality score is calculated by comparing the learning implementation score to the maximum possible score. The total score is then divided by the highest score and multiplied by 100%. Once the percentage is obtained, the results are grouped according to the criteria outlined by Vela (2021), as follows.

Table 2. Practicality criteria

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

The effectiveness of using the augmented reality-based mathematics learning application with multiplication material is assessed through student response questionnaires. Data on student responses are collected by having students fill out questionnaires, with assistance from teachers, after using the augmented reality application. The questionnaire included 15 items designed to assess students' perceptions, interests, motivations, and reactions to using the augmented reality application for learning multiplication. The data from the student response questionnaires are calculated to determine the percentage of positive responses to the augmented reality mathematics learning application. The student responses are measured by dividing the total score by the maximum possible score and then multiplying the result by 100%. The obtained percentage is then grouped according to the criteria presented in Table 3.

Table 3. Student's response criteria

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

The effectiveness of using augmented reality applications in multiplication material, as well as the values obtained from the pretest and post-test carried out during the learning process, is analyzed using N-Gain. N Gain core is calculated using the equation developed by (Hake, 1998) as follows:

$$N - Gain = \frac{Score\ Posttest - Score\ Pretest}{Score\ Maximum - Score\ Pretest}$$

This N-Gain provides an overview of the extent to which student learning outcomes increase after the learning process, taking into account the student's initial level of understanding.

Table 4. N-Gain score criteria

No.	Interval	Criteria
1	N-Gain > 0.7	High
2	0.3 ≤ N-Gain ≤ 0.7	Medium
3	N-Gain < 0.3	Low

▪ RESULT AND DISSCUSSION

The Development of Augmented Reality Application

Define Stage

At the define stage, the researcher collected initial data from teachers and students to assess the state of the school and classroom conditions regarding the use of learning media. This was done through interviews and observations to understand the existing classroom environment. The researcher selected basic multiplication as the mathematics learning material because students, especially those with special needs, have faced difficulties in finding concrete examples of the subject, and this choice was approved by the teachers.

The define stage also focused on creating educational game designs. Storyboards play a crucial role in multimedia development, particularly in the early stages leading up to the design phase. A storyboard is a graphical representation that uses images and a series of illustrations to visualize the sequence of interactive media, including animations. Below is an overview of the storyboard used in the development of the augmented reality application for children with special needs.

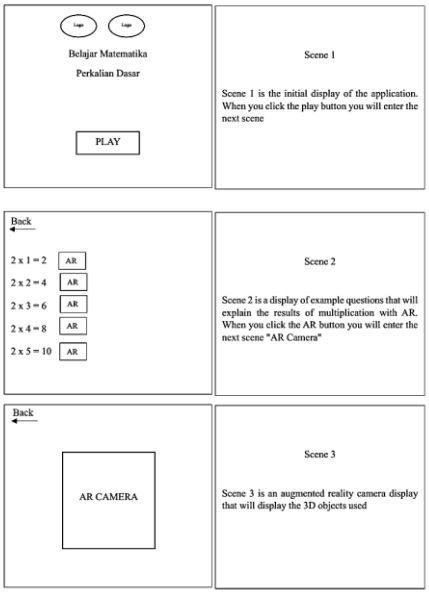

Figure 1. AR application storyboards

In the storyboard, Figure 1 is the initial process in creating an AR application. Scene 1 contains the initial appearance of the application and when the play button is clicked, users can enter the next scene. In scene 2, there is a display of example questions that will explain the results of multiplication with AR. If the AR button is clicked, users enter the next scene "AR Camera". Scene 3 is an augmented reality camera display displaying the 3D objects used.

In the storyboard, Figure 1 represents the initial stage of creating the AR application. Scene 1 shows the application's main interface, and when users click the "play" button, the next scene is proceeded. Scene 2 presents example multiplication questions, which are explained through augmented reality (AR). When users click the "AR" button, they move on to the next scene, labeled "AR Camera". Scene 3 is where the AR camera display is activated, showing 3D objects related to the multiplication concept, enhancing the learning experience for the students.

Design Stage

The design stage follows the define stage and serves as a foundation for developing the AR application. In this stage, the application is specifically designed to meet the needs and characteristics of children with special needs. The choice of media and learning materials is carefully tailored based on the analysis conducted during the define stage and the storyboard creation process. The goal is to ensure that the design aligns with the

educational requirements and learning preferences of the target students. Below is an overview of the AR application design.

Figure 2. Application display

In Figure 2, the opening screen of the augmented reality application is shown. Students can click the "play" button to begin their mathematics learning activities, focusing on basic multiplication. Once the "play" button is selected, students are presented with the multiplication material and its results. After reviewing the material, students can click the "AR" button to proceed. They will then scan the provided marker to activate the augmented reality features of the application.

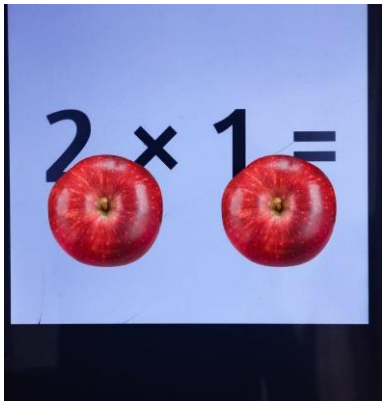

Figure 3. AR camera scan results

In Figure 3, the result of the AR camera scan is displayed. Students can view the multiplication results in 3D, providing a tangible, visual representation of the concepts. This 3D visualization serves as a concrete example, which is especially beneficial for children with special needs. Such features address a key need in classroom learning activities, offering a more interactive and engaging way for students to understand and apply basic multiplication concepts. This approach is something teachers find highly valuable for enhancing students' comprehension.

Develop Stage

After the design stage is completed, the next step is the development stage. During this stage, the feasibility of the augmented reality application is validated. Validation is

conducted to assess the quality and effectiveness of the application, and it involves feedback from four experts: two informatics engineering lecturers from Institut Teknologi dan Bisnis Bina Sarana Global and two mathematics teachers from SKh YKDW 01 Tangerang. This expert evaluation helps ensure that the application meets the required standards for usability and educational value.

Table 5. Expert validation results

No.	Assessment Aspect	Score				Percentage	Category
		V1	V2	V3	V4		
1	Material	0.90	0.92	0.92	0.91	92%	Very Valid
2	Media Design	0.91	0.90	0.92	0.90	91%	Very Valid
3	Appropriateness of Content	0.90	0.92	0.94	0.90	90%	Very Valid
Average		**0.90**	**0.91**	**0.93**	**0.90**	**91%**	**Very Valid**

Based on this data, it can be concluded that the material in the augmented reality application received a validity score of 92%, indicating that the material is very valid and suitable for use by students. The media design of the augmented reality application received a score of 91%, which means the design is very valid and appropriate to be used by students. Additionally, the content appropriateness of the augmented reality application scored 90%, confirming that the content is valid and suitable for student learning.

The validation results of the augmented reality application yielded an average score of 91%, which falls within the very valid category. Based on the score interpretation criteria, the application is deemed highly valid and suitable for use. Therefore, it can be concluded that the augmented reality learning media for multiplication is very appropriate for children with special needs.

The implementation of the augmented reality learning media was conducted over three sessions focused on the multiplication process material. In each session, students engaged in mathematics learning using the augmented reality application, beginning with an explanation from the teacher on how to use the app. Students then studied the material and participated in learning activities based on the content and instructions provided by the augmented reality application, which guided them through the multiplication concepts.

The results of the development trials provided data on the implementation of learning using the augmented reality learning media application in mathematics, specifically for multiplication material. This was assessed by four expert observers. The analysis of the learning process implementation can be found in Table 6. It presents the data gathered from the expert assessments, which helps evaluate the effectiveness and practical application of the augmented reality learning media during the lessons on multiplication.

Table 6. Practicality data results

Learning Meeting	Score				Percentage	Category
	O1	O2	O3	O4		
1	0.93	0.92	0.92	0.94	92%	Very Practical
2	0.94	0.92	0.94	0.92	94%	Very Practical

3	0.92	0.93	0.94	0.93	93%	Very Practical
Average	0.93	0.92	0.93	0.93	93%	Very Practical

The results of the observations on the implementation of learning using the augmented reality learning media application in mathematics for multiplication material, conducted over four lessons, reached 93%, which is above the efficient criteria. The application of augmented reality learning media is deemed suitable for use in mathematics learning for multiplication, and the activities in the learning plan were successfully implemented. These findings are consistent with research conducted by Andzin (2024), which shows that technology-based developments, such as augmented reality applications, can serve as a motivating tool for learning and improve the basic mathematics skills of children with special needs.

Disseminate Stage

The next phase after the develop stage is the disseminate stage, where field trials are conducted to assess student responses to the augmented reality application. During the trial, evaluations were carried out by respondents, consisting of 5 students sitting in 6th-grade at SKh YKDW 01 Tangerang. These students used the augmented reality application focused on basic multiplication material over three sessions during the learning process. This trial aimed to gather feedback on the effectiveness and engagement of the application in enhancing students' understanding of multiplication concepts.

Figure 4. Application usage

Students' responses were collected using a questionnaire to assess the effectiveness of the augmented reality learning media application in mathematics learning. The analysis of the students' response results is presented in Table 7, which provides detailed feedback on how the students engaged in and perceived the application during the learning process. This analysis helps evaluate the overall effectiveness, the users experience, and the impact of the augmented reality application on students' learning outcomes.

Table 7. The students' responses to the ar application

No.	Assessment Aspect	Percentage	Category
1	Motivation	94%	Very Good
2	Interest	95%	Very Good
3	Feedback	92%	Very Good

Average	**93.67%**	**Very Good**

Based on the analysis results, the average percentage for the three assessment aspects motivation, interest, and feedback—reached 93.67%, placing it in the very good category. The motivation aspect received a percentage of 94% (very good category), the interest aspect received 95% (very good category), and the feedback aspect received 92% (very good category). These results indicate that the implementation of augmented reality learning media in mathematics has made the learning process more engaging, interactive, and effective. The use of 3D images that are more realistic and aligned with everyday life has helped students find the material easier to understand, which in turn has increased their enthusiasm and prevented boredom during lessons. Furthermore, the use of augmented reality has been designed to enhance students' motivation, helping them engage more actively with the material and study module. This aligns with the findings from the previous research (Ivan et al., 2024), which highlights the positive impact of augmented reality on students' learning motivation and engagement.

The Effectiveness of Augmented Reality Application

The effectiveness of the augmented reality application is reviewed by comparing the N-Gain scores on each indicator of use augmented reality applications in multiplication material through the pre-test and post-test tried on students. A pre-test was given to students before they were given treatment for learning multiplication material without using an augmented reality application. After the development product was implemented in learning, students' basic mathematical abilities are repeated in multiplication material with a post-test. The pretest and post-test results were assessed by reviewing each indicator and analyzing the N-Gain score for each indicator of the use of augmented reality applications in multiplication material. Overall, implementing learning with augmented reality applications on multiplication material provides positive improvements for every students with special needs. N-Gain Score results for using augmented reality applications in multiplication material indicators are presented in Figure 5.

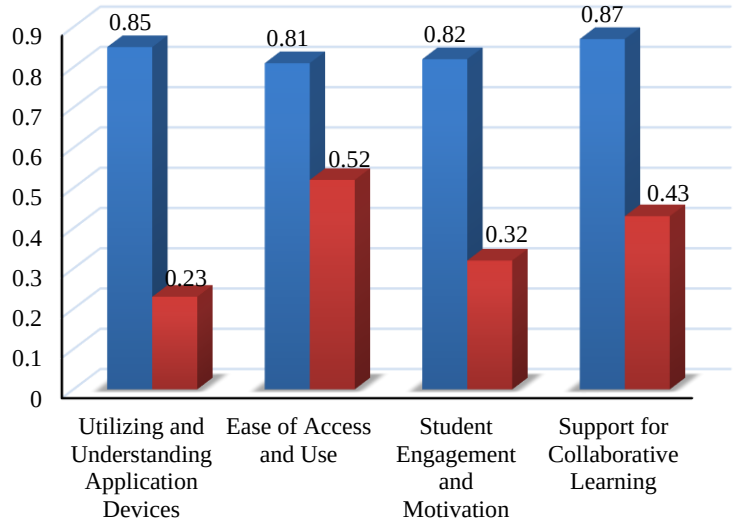

Figure 5. The comparison between n-gain of experimental and control classes

The first indicator is utilizing and understanding application devices in the experimental class observed by looking at students' abilities in using augmented reality applications, such as being able to open menus on media and access augmented reality applications. The N-Gain score for the experimental class was 0.85 with a high category, while the N-Gain score for the control class was 0.23 with a low category. In the experimental class, they have been able to use augmented reality applications well in multiplication material. Meanwhile, in the control class, students did not understand how to work with the material given directly, and there are some factors that caused the control class to be lower; one of which was that the class was not conducive enough. This research is supported by Ivarson et al., (2024), who states that effective use and understanding of application tools have the potential to improve learning outcomes significantly. However, it is essential to focus not only on the availability of technology but also on ensuring that students and educators are proficient in using those tools. By overcoming challenges and implementing effective implementation strategies, educators can harness the full potential of digital learning tools to improve student learning.

A former research by Fernández-Batanero (2022) found that augmented reality is highly motivating, as it can enhance students' engagement and interest in class activities. Moreover, it can offer valuable support to students with special educational needs.The use of this application can be implemented in other schools with limited technology, as it is easy to install without requiring much internet access. A user manual can also be provided to help teachers, parents, and assistants use the augmented reality application effectively, to teach students with special needs using the application properly. The further development of augmented reality (AR) applications can significantly enhance the learning experience, especially for students with special needs. One promising direction is the integration of AR with other technologies, such as artificial intelligence (AI), to personalize the learning experience. By integrating AR with AI, the system can adapt content to suit the individual needs of each student. For example, if the AI detects that a student is struggling with a specific concept, the AR application could provide additional simulations, visualizations, or simpler explanations tailored to that student's learning pace and style.

The second indicators is the ease of access and the use of augmented reality applications in the experimental class were observed by looking at students' ability to easily scan the AR camera which would then produce 3D images in accordance with examples in everyday life. The N-Gain value for the experimental class was 0.85 in the high category, while the N-Gain value for the control class was 0.52 in the medium category. In the experimental class, an AR camera scan can be utilized to scan the markers provided. Meanwhile, in the control class, many students understood how to work on the material given directly. This is in line with research conducted by Basumatary et al., (2023) AR-based applications can motivate students and increase their perception of knowledge. Furthermore, it can enhance students' learning with multimedia images, 3D objects, and animations. Apart from that, students can interact with the AR-based application in their learning process. This kind of interactive learning environment generally benefits students in terms of understanding and avoiding misunderstandings.

The third indicator of students' engagement and motivation for implementing augmented reality applications in the experimental class was observed by seeing that the use of AR applications in learning can significantly increase students' involvement and

motivation. AR applications provide a more immersive and interactive experience that can help students understand the material better, be more interested and be more motivated to learn. The N-Gain value for the experimental class was 0.82 in the high category, while the N-Gain value for the control class was 0.32 in the medium category. In the experimental class, students showed higher motivation to learn because learning became more fun and contextual. This research is supported by Ziden et al. (2022). Augmented Reality (AR) applications in creating students' involvement and motivation have shown great potential in improving the learning experience. The use of AR in learning can increase students' engagement in various ways, be it cognitively, emotionally, and socially. Additionally, it enhances students' motivation to learn.

The fourth indicator of support collaborative learning for the implementation of augmented reality applications in experimental classes is observed by seeing that collaborative learning with AR involves the use of AR technology to facilitate interaction between students, allowing them to work together to solve problems, visualize material, and share learning experiences. The N-Gain value for the experimental class was 0.87 in the high category, while the N-Gain value for the control class was 0.43 in the medium category. In experimental courses, students can interact with virtual objects in the real world, which creates opportunities for more active and meaningful collaboration. This research is supported by Kuanbayeva et al. (2024), who stated that R can strengthen cooperation among students by allowing them to interact in an immersive and 3D-based learning environment. AR therefore, improves students' communication and engagement in the collaborative learning process, as it gives them the opportunity to explore and manipulate virtual objects together.

Overall, the N-Gain score for the experimental class was 0.84 in the high category, and the control class was 0.34 in the medium category. A significant difference in N-Gain between the control and experimental classes could occur due to various factors. In the experimental class, AR applications allowed students with special needs to interact directly with learning materials, such as 3D objects or simulations, facilitating a deeper understanding of concepts than the control class. However, other factors such as students' readiness, teaching quality, the devices used, and assessment methods also play an essential role in the learning outcomes.

Other factors contributing to the significant difference in N-Gain between the experimental and control classes are most likely the ease of direct interaction with learning materials, increased engagement and motivation, and the personalized learning experience supported by AR technology. Additionally, other positive influences, such as collaborative learning and direct feedback, also serves as a key role in enhancing the understanding and math skills of students with special needs. These factors explain why AR can be more effective in supporting learning outcomes compared to conventional teaching methods (Pan, 2022).

Analysis of Students with Special Needs when Interacting with AR Applications

During the learning process, students with special needs are guided by the teacher and the observation team, starting from how to scan the AR camera using the application. The AR element students enjoy the most is when they scan the AR camera and 3D images appear. The 3D images show the shapes of everyday objects, providing real-life examples during the learning process. There are no technical issues throughout the learning

activities because the AR application can be used without an internet connection and can be installed on Android smartphones. The installation process is easy for teachers and the assistants of students with special needs to understand. The augmented reality application can be used anytime and anywhere, making it easy to use across various groups. Therefore, this application can be utilized by both schools and parents with limited internet access.

The above condition is supported by research by Intara preecha et al. (2023), who found that the use of augmented reality (AR) in mathematics learning for children with special needs has become a topic that has increasingly attracted the attention of researchers in recent years. AR technology provides an immersive and interactive learning experience, which can help children with special needs access and understand abstract mathematical concepts in a more concrete and fun way. A number of studies show that AR is very effective in increasing the engagement, understanding, and math skills of children with special needs.

Limitations of the Research and Challenges in the Implementation of AR Applications

The limitations of this study are due to the small sample size, as there were only 6 students with special needs in one class. The potential bias of a small sample size can limit the ability to generalize the results to a larger population. Take for example, the study is conducted with a small group of students. In that case, the findings may not reflect how AR applications work for a more diverse group of students regarding age, educational background, and technological ability. In addition, the involvement of the teacher in the effectiveness of learning using AR is crucial. The success of using AR in education depends on the technology and how the teacher integrates it into the learning process.

The main challenges in implementing augmented reality (AR) in education, especially for students with special needs, offer many benefits but encounter several key obstacles, such as the availability of AR devices, internet access, and teachers' readiness. The devices required to run AR applications, such as smartphones or tablets with sufficient cameras and processing power, may need to be made available in adequate numbers. Nevertheless, such facilities might be too expensive for particular schools, especially in areas with limited budgets. This can become a barrier to implementing AR in the classroom. One solution is to use the existing devices by ensuring that AR applications can run on older devices with lower specifications, therefore, schools do not need to purchase new equipment.

Moreover, AR applications typically require a stable and fast internet connection to access or download content. In areas with limited internet access, this can pose another significant challenge to the use of AR effectively in the classroom. To overcome this, AR applications should be such designed to function offline, enabling its use without requiring an active internet connection. To optimize the utilization of AR technology in schools where budget and teachers' readiness are the main issues, here are some recommendations for teachers' training and modifications to AR applications to make them more affordable.

It is suggested that training should be carried out in a practical way, focusing on how to use AR applications in specific learning contexts. Teachers should be allowed to

try out the applications and design AR-based activities for their own students. Training activities, as conducted by Ferawati et al. (2023), in which teachers create learning media such as augmented reality applications, can help teachers support learning for students with special needs. Through these strategies, AR will become a more affordable, practical, and accessible tool for various educational settings, improving the quality of learning and enabling more students to benefit from this technology.

▪ CONCLUSION

Based on the research results from the validation of the augmented reality application, the application achieved an average score of 91%, which places it in the very valid category. According to the score interpretation criteria, this indicates that the augmented reality application is highly valid and suitable for use, especially for children with special needs. Specifically, the material within the augmented reality application scored 92%, confirming that the content is very valid and appropriate for student use. The media design of the application received a score of 91%, indicating that it is valid and suitable for students. The content suitability scored 90%, which also affirms that the content is valid and can be effectively used by students. In terms of the learning implementation, observations during three lessons showed an efficiency score of 93%, which is highly positive. The average percentage for the three key assessment aspects—motivation, interest, and feedback—was 93.67%, placing it in the very good category. This demonstrates that the augmented reality learning media in mathematics, particularly for multiplication material, is effective and suitable to be used by children with special needs to improve their basic mathematics skills. N-Gain score for the experimental class was 0.84 in the high category, which also affirms that the AR is very effective in increasing the engagement, understanding, and math skills of children with special needs. The augmented reality learning media application can be a useful tool to help students, particularly those with special needs, to better understand multiplication material. In additions, it offers an interactive, engaging, and effective way to learn basic math skills. Augmented reality applications can be a valuable teaching tool in mathematics, providing a fun and engaging learning environment. Teachers can use this tool as an alternative to traditional methods, helping to capture students' attention, increase their enthusiasm for learning, and improve their understanding of the material.

Suggestion for further researches could encompass the consideration of integrating other subjects with the use of augmented reality applications and explore the use of game-based learning media to support educational activities, especially for fun and engaging mathematics lessons. The expansion to other subjects to see how augmented reality and similar technologies can improve students' abilities across different areas of learning. Additionally, combining augmented reality with other learning methods may offer more diverse and effective ways to enhance student learning experiences. These findings contribute to the growing body of knowledge on how technology, particularly augmented reality, can support and enhance the learning experiences of children with special needs, particularly in foundational areas like mathematics. In order for this AR application to be utilized on a larger scale, it would be beneficial to provide institutional licenses or mass distribution through platforms like the App Store for Education or Google Play for Education. Potential barriers may arise for schools or students who have inadequate hardware (such as smartphones with low specifications), limitations in graphics

processing, and constraints in object recognition. To address this, an optimal approach would be to ensure that the application runs smoothly on a variety of devices with lower specifications. Considering the utilization of web-based AR (WebAR) to reduce dependence on specific hardware should also be taken into account.

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