Utilizing Augmented Reality in Digital Literacy Education for Primary School Students with Special Needs

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Manuscript received July 31, 2024; revised August 19, 2024; accepted October 25, 2024; published February 17, 2025

***Abstract*—This article examines the use of augmented reality in teaching digital literacy to primary school students with special educational needs. The study also explored the main challenges in teaching digital literacy to participants, such as the lack of personalized learning opportunities and limited accessibility. To address this issue, we used an augmented reality mobile application for continuous communication and interaction with students and teachers to improve access to educational materials. To this end, an experiment was conducted with participants using an augmented reality mobile application to evaluate its impact on learning. The participants were 20 students; 10 were in a control group, and 10 were in an experimental group. We also included 5 digital literacy teachers and five parents in the data collection. The results showed the positive effects of augmented reality on achievement. We conclude that augmented reality technologies can create unique interactive learning environments that enrich the learning process and provide immediate feedback, essential for students with special needs. The article offers examples of how augmented reality can enhance students' learning with hearing and motor disabilities. In addition, we provide recommendations for integrating augmented reality into educational programs and suggestions for improving educational practices with augmented reality technologies.**

***Keywords*—augmented reality, inclusive education, digital literacy, primary school, digital content**

I. Introduction

In the age of digitalization [1], education has become a key factor for social integration and personal growth. Inclusive education deserves special attention in this context [2]. Inclusive education ensures equal access to knowledge for all categories of children including those with Special Educational Needs (SEN) [3]. Digital literacy, as a fundamental part of modern education, should be accessible to everyone, regardless of individual characteristics.

In Kazakhstan, computer science education in primary school has been changing [4, 5]. Since January 2022, the subject of computer science began in the first grade under the title "Digital Literacy." Previously, teaching started in the third grade as Information and Communication Technology (ICT) [6]. The development of the digital world and students' early use of gadgets make it necessary for them to acquire digital skills at an early age [7]. The national government has included this subject in the curriculum to ensure its development as effectively as possible. Computer science educators are facing new challenges in teaching digital skills.

The introduction of Augmented Reality (AR) technologies into the educational process [8] opens up new horizons for inclusive learning and enables the creation of unique interactive and immersive learning environments [9]. These technologies enrich the learning material and provide fast and ultra-fast feedback, which is key to effective learning and customization of the course to the individual learner [10]. Virtual reality and AR feedback allow students to instantly assess their performance and make adjustments in real-time, leading to deeper understanding and better learning skills.

In addition, using a mobile application with AR [11] is essential for creating an accompanying educational environment as an element of constant communication and interaction between primary school students and teachers. AR-enabled mobile applications can be a platform for sharing resources, providing feedback, and supporting students by providing constant access to learning materials and resources, which is especially important for students with disabilities. The authors of this article have some experience working with groups of students with SEN and aim to provide findings that engage a wider range of teachers working with them while exploring the possibility of using AR to improve the quality of teaching.

There are very important problems in teaching students with disabilities today:

- Lack of personalized learning, as the specific learning needs and pace of students with disabilities are not taken into account, making it difficult for these students to interact with and understand the teaching material [12].
- Limited accessibility, as many educational resources and environments are not designed for accessibility, makes it difficult for students with physical, sensory, or cognitive disabilities to participate fully in learning activities [5, 6, 10, 11].

One possible solution to the above problems is the introduction of assistive technologies such as AR in learning. The article discusses the possibilities of AR to improve the quality of education for students with hearing disabilities, intellectual disabilities, musculoskeletal disorders, and severe speech disabilities.

This article explores and analyzes the potential of AR in teaching the digital literacy course to primary school students with SEN. The article aims to demonstrate how AR can improve the accessibility and effectiveness of learning for these categories of students. It will also look at practical examples from the author's mobile assistive technology application for teaching with AR. An important aspect is identifying the challenges and limitations of educational institutions in integrating AR technologies into the educational process and offering solutions to overcome these difficulties. The article's main aim is to highlight the potential

doi: 10.18178/ijiet.2025.15.2.2248

benefits of AR for improving the educational experience and to stimulate further research and development in this area. How does the use of AR improve access to and understanding of digital literacy for primary school students with SEN?

What are the specific benefits of using AR technology for students with different types of disabilities (hearing disabilities, motor disabilities, etc.) in the educational process?

How does the continuous interaction enabled by a mobile AR application affect communication between students and teachers in inclusive education?

Significance: This study contributes to the emerging field of AR in education by exploring its potential to improve students' digital literacy with SEN. The study is relevant for educators, developers, and policymakers as it demonstrates how AR can create more interactive and accessible learning environments. The purposes of this article are to:

Analyze the potential of AR in teaching digital literacy to primary school students with SEN.

Evaluate the effectiveness of AR-based mobile applications as tools for continuous communication and interaction between students and teachers.

Provide practical examples of how AR can enhance the learning experience of students with disabilities.

Identify the challenges and limitations of integrating AR technologies into educational programs and suggest ways to overcome them.

II. Literature Review

A. Educational Program

The digital literacy educational program must be tailored to each child's needs to ensure optimal learning. These needs are fundamental for inclusive schools [2].

Kaffenberger [13] has suggested that inclusive schools should use a standard educational program adapted to individual students' needs. Accordingly, educational program modifications may include time adjustments, materials, learning processes, and classroom management tools. This allows students to realize their potential and develop unique talents and abilities [14].

B. Using a Mobile Application with AR in Education

The developed mobile application corresponds to one of the five types of AR applications in education proposed by Yuan *et al.* [15], such as Object Modeling (OM), which helps students obtain instant visual information about the appearance of a given object from different perspectives. The resulting 3D models can be rotated, color-adjusted, and stylized to convey learning content from various perspectives. Erni *et al.* [16] have shown that while AR cannot be used as a stand-alone learning tool like other forms of e-learning, it can help teachers transfer knowledge to students. In the context of inclusive education, AR tends to impact students positively and is liked by them. This suggests that AR can be helpful as a learning tool in inclusive education.

Students with intellectual disabilities may have difficulty performing everyday tasks. Turan and Atila [17] believe that AR games can be an effective learning tool for them.

The study's overall results [18] showed that AR technology effectively supports the learning of students with specific learning difficulties. These students were willing to use it and found it attractive.

A study by Baidrakhmanova *et al.* [19] aimed to design, create, and evaluate an innovative teaching material, AR, to investigate its impact on the motivation and collaboration of secondary school students. It also explored the possibility of improving students' social and digital skills using a situational approach in a mobile learning scenario.

The results of Rakhimzhanova *et al.* [20] show that AR cannot be used in schools like conventional e-learning tools. However, its use can help teachers to impart knowledge to students. In inclusive education, students often assess the use of AR positively.

C. Teaching Computer Science to Students with SEN

While a significant body of research shows how information and communication technologies [21–23] can help schools and teachers make their teaching more inclusive, more evidence is needed to describe how best to make computer science teaching itself inclusive.

Ludi and Reichlmayr [24] reviewed the literature on inclusive education in school computer science classes. It identified several inclusive practices, including providing a relevant and authentic curriculum that focuses on depth of understanding, promoting culturally relevant tasks, and providing an inclusive environment that counters bias. The review also addresses further research on what constitutes an inclusive computing classroom.

Students with SEN are often at risk of being excluded from computer science lessons. Ludi and Reichlmayr [25] highlight three aspects of this exclusion: teacher attitudes and expectations, pedagogical approaches, and accessibility. Teachers' attitudes may negatively impact student achievement in computer science classes if they set lower expectations due to students' particular needs. These students require unique resources or approaches to access the educational program. For example, students with visual disabilities continue to be underrepresented in computer science education. Promoting culturally relevant activities can be effective for students of all ages. Block-based programming languages such as Scratch are increasingly used when introducing students to computer technology. However, they may not be accessible to visually impaired students [24].

Inclusive practices in all subjects (e.g., use of Braille, time to navigate, etc.) were complemented by computer science-specific approaches: fully annotated source code and a screen reader configured to read all punctuation. These practices helped students to solve complex problems [26, 27].

The approach proposed by Palieraki and Koutrouba [28] and colleagues was to use 3D printing to create accessible computer science learning resources for individuals with visual disabilities, including concepts such as data structures. They found that sighted students successfully used the resources they made, which could also be used in inclusive classrooms.

Problems in managing the behavior of students with social, emotional, and behavioral difficulties in the classroom are a concern of educational professionals. The authors relied on an analysis of studies from 2000 to 2017 in the ERIC, Web of Science, FRANCIS, and MEDLINE databases. Inclusion criteria included: (i) interventions aimed at improving the behavior of students with disruptive behavior in school; (ii) primary school students aged 6–11 years; (iii) the presence of a measurable outcome related to social/emotional/behavioral indicators; (iv) the use of single designs and recommendations for future applications [4].

A previous article [29] examined the effectiveness of differentiated ICT teaching in Greek primary schools. Differentiated instruction improved students' grades and activity levels. The strategy of flexible grouping, the "thumbs up" method, and differentiated work plans were particularly effective. However, due to its complexity, asynchronous work combined with hierarchical learning activities was challenging for educators.

One of the goals of the Republic of Kazakhstan's curriculum for the course "Digital Literacy" is to develop computational thinking [30]. Now, the question arises as to whether students with SEN have difficulties developing computational thinking.

Sternberg and Grigorenko [30] suggest that educators can incorporate several essential computational thinking practices and skills into their instruction to improve students' problem-solving and critical-thinking skills. Decomposition, breaking problems into smaller parts to facilitate problem-solving. Pattern recognition recognizes recurring features, data, or relationships to identify patterns and trends. They select tools and the appropriate computing device to complete a task efficiently. Teachers can help students better understand the content through these practices and skills. Educators can combat educational inequities by using inclusive practices and strategies that promote access and participation for all students. By incorporating these inclusive pedagogies and strategies into their instructional practices, educators can create more accessible and equitable learning environments that support all students' diverse needs and experiences.

Wang *et al.* [31] examined the case of an eleven-year-old boy who is passionate about technology, particularly robotics. The researchers used an experimental approach to improve his concentration by working with robotics, which impacts the educational process and overall development. The study shows that with age and increasing interest in robotics, a boy's concentration, and psychomotor coordination improve, positively impacting the educational process and daily life. Robotics also promotes personal and academic development.

The article's authors developed the digital literacy course using Sternberg's well-known 7-step problem-solving model. This model comprises the stages, including problem identification, problem definition, strategy building, information organization, resource allocation, monitoring, and evaluation of problem-solving [22]. These stages of the problem-solving process require a person to organize each step and make decisions simultaneously. In addition, the learner must gain experience and strength for the problem-solving process to continue accomplishing the task [32]. Problem-solving skills potentially impact the independence and academic performance of individuals with intellectual disabilities.

By using schema-based learning in the hands-on teaching of problem-solving skills to students with mild intellectual disabilities [33, 34], these students can benefit from many learning features [35]. For this reason, visual representation is very important for special education students [36]. Problem-solving processes involve some thinking strategies. The most common are algorithmic thinking and computational thinking [37].

Demirdag [38] does not mention methods and technologies to improve the social participation of students with special needs. However, based on the context of their study, the following techniques and technologies can be used to improve the social adaptation of students with special needs in school. Use of adaptive technologies: the introduction of technologies that help students with special needs in the educational process, collaboration between teachers, researchers, parents, and others involved in the educational process to create a supportive and inclusive environment for students with special needs.

The research findings [39, 40] emphasize the importance of inclusive education and the role of educational leaders and teachers in creating a supportive learning environment for all students that contributes to their successful learning and development. Research hypothesis: If you use a mobile application with AR technologies as part of a teaching experiment to teach digital literacy to students with SEN in primary school, the experimental group's results will be higher than those of the control group.

In developing the author's mobile application, we followed some models for developing VR educational environments and the role of immersion technologies in healthcare, as described in the book [41]. A monograph highlights AR's educational possibilities and comprehensively studies about its application [42]. In addition, a book published by Akcayir and Demmans [43] focuses on mobile learning, formal and informal education, and the challenges for educators when using AR/VR in teaching.

III. Materials and Methods

The study's main methods included qualitative and quantitative approaches that help evaluate the effectiveness of AR technologies and their practical application in primary schools.

At the beginning of the experiment, we surveyed teachers and parents of students with special education needs to identify existing problems of inclusive education in primary schools.

During the experimental process, we conducted control tests to measure the extent of mastery of educational material on digital literacy [12] in the control and experimental groups. In the latter, we implemented instructions using a mobile application with AR.

Following the experimental process, we conducted interviews with the experimental group of students with SEN and their parents to assess perceptions and attitudes toward the use of AR.

A. Research Design

The study design used a experimental design with Kazakhstani primary school students. The participants were students with hearing impairments, intellectual disabilities, musculoskeletal disorders, and severe speech disabilities who used a developed mobile application with AR in the digital literacy course to determine whether the use of this mobile application had an impact. To ensure and increase reliability, we conducted a pilot study with teachers, parents, and student participants using a Google form.

The methodology we followed to administer the survey is as follows:

1) Received informed consent from all participants.
2) Information confidentiality conditions.

B. Sampling and Data Collection

To participate in this research, we considered the following criteria:

1) Target group: Primary school students with SEN (students with hearing disabilities; students with mental retardation; students with musculoskeletal disorders; students with severe speech disabilities).
2) Number of participants: 30 students, divided into a control group and an experimental group with 15 participants. 5 digital literacy teachers and 5 parents of students with SEN.

The study's main methods included qualitative and quantitative approaches that helped evaluate the effectiveness of AR technologies and their practical application in educational institutions. Qualitative methods used:

The first stage of the experiment was pre-testing questionnaires to assess the level of motivation and engagement, observations, and interviews with teachers and parents to assess students' initial level of knowledge, motivation, and engagement.

In the second stage, experimental and control groups were determined. The experimental group was trained using a developed mobile application with AR during the school year, while the control group followed the traditional program.

The first and second stages of the research involved qualitative methods, and the subsequent stages involved quantitative research methods.

In the third stage, we used an experimental design to compare the results by implementing an adapted digital textbook using an AR mobile application and a digital textbook without AR. Data collection tools were administered before and after the course to evaluate students' knowledge and skills.

In the fourth stage, quantitative data were collected and analyzed. Quantitative analysis methods were used to compare test results [(t-test or analysis of variance (ANOVA)] to determine statistically significant differences between groups. We used a *t*-test to determine whether there was a statistically significant difference in the mean scores of the two groups.

The empirical value in the *t*-test obtained in the experiment exceeds the tabulated value $8.9098>2.1009$; therefore, there is reason to accept the alternative hypothesis (H_1) that students in the experimental group showed a higher level of knowledge.

Table 1 shows the criteria for assessing students in Grade 3 about programming in the digital literacy course.

Table 1. Assessment criteria

Percentage (estimate)	Mastery of material (criteria)
90–100	A student with SEN demonstrated a deep understanding of working with instant messengers in joint projects, accurately and completely explains how to exchange information online, and strictly follows security rules. Excellent execution of practical tasks: exceptionally implements complex repetition algorithms in Scratch, creates complex games with advanced use of character movement algorithms, demonstrating creativity and innovative solutions.
75–89	A student with SEN correctly uses instant messengers to collaborate on a project, correctly explains how to exchange information online, and follows Internet safety rules. Effectively complete practical tasks: confidently implements repetition algorithms in Scratch, creates functional games using character movement algorithms.
50–74	A student with SEN can use instant messengers to work on a project, but does so with errors; explains how information is shared online, but not always accurately. Basic implementation of practical tasks: implements simple repetition algorithms in Scratch, but makes mistakes; creates basic games with limited use of motion algorithms.
0–49	A student with SEN cannot use instant messengers to collaborate, does not explain how to exchange information online, and does not follow basic Internet safety rules. Lack of practical application of knowledge: does not implement repetition algorithms in Scratch, does not create games using character movement algorithms.

C. Data analysis

Based on the data analysis, the following results can be drawn:

1) The experimental group using AR received higher grades, an average of 86.2%, compared to the control group, which received a 71.3% performance. Thus, it can be concluded that AR generally increases academic performance.
2) The standard deviation of the results achieved by the experimental group is 4.73, compared to 2.36 for the control group. These data show that the experimental group's results are highly scattered (heterogeneous) compared to the control group. Some students achieved significantly better results through the introduction of AR.
3) However, by calculating the significance criterion for the t-test results (Eq. (3)), it is possible to confirm the alternative hypothesis (H_1) that the students in the experimental group have a higher average level of knowledge.

IV. Results

A. Pedagogical Experiment

In a pedagogical experiment, the effects of AR on teaching digital literacy to primary school students with disabilities were investigated. Two teaching methods were compared: one with AR technology and a control group without AR. The experiment aims to test and evaluate the effectiveness of the proposed educational methodology for teaching the course digital literacy to students with special needs using AR.

B. Ascertaining Experiment

In the first stage, a confirmatory experiment was conducted using a questionnaire (Figs. 1 and 2), a survey, an interview, and videoconferences with teachers and parents of students in primary schools of inclusive education in the Republic of Kazakhstan. Based on the questions, we explored this topic in more detail (for example, in the "Programming" section, Table 2). The study involved 105 teachers and 80 parents.

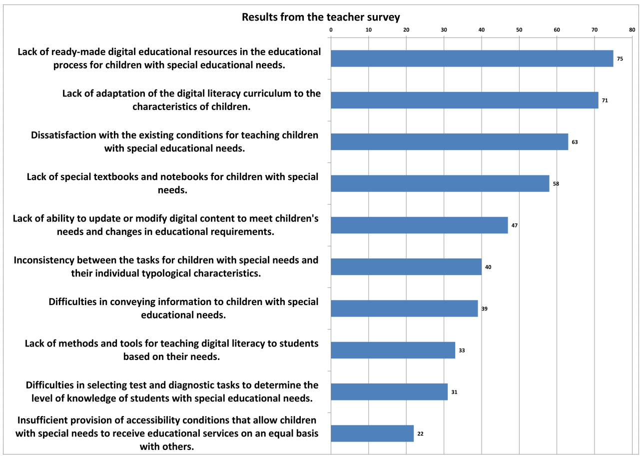


Fig. 1. Results from the teacher survey.

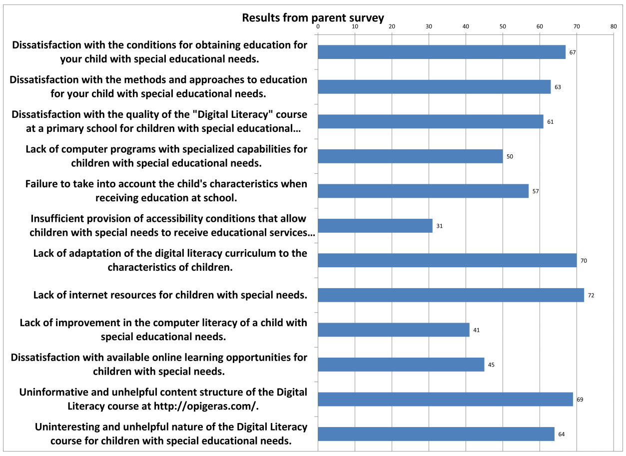


Fig. 2. Results from parent survey.

Table 2. Discipline "digital Literacy," 3rd grade

Section	№	Lesson topics	Learning Objectives	Number of hours	Terms
Information etiquette	1	Communication on the Internet	3.3.2.1 use instant messengers to collaborate on a project; 3.3.2.2 explain ways to exchange information on the Internet; 3.1.3.1 follow the basic rules of personal safety when working on the Internet	1	1st week
	2	Methods of exchanging information on the Internet	3.3.2.1 use instant messengers to collaborate on a project; 3.3.2.2 explain ways to exchange information on the Internet; 3.1.3.1 follow the basic rules of personal safety when working on the Internet	1	2nd week
Programming	3	Repetition in our lives	3.4.1.1 develop a repetition algorithm in the programming environment (Scratch) according to a given scenario;)	1	3rd week
	4	Cycles	3.4.1.2 implement the repetition algorithm, specified in verbal form, in the programming environment (Scratch)	1	4th week
	5	The "repeat for… times" cycle	3.4.1.2 implement the repetition algorithm, specified in verbal form, in the programming environment (Scratch)	1	5th week
	6	The "repeat until…" cycle	3.4.2.4 implement a repetition algorithm when creating a game in a programming environment (Scratch)	1	6th week
	7	Character movement	3.4.2.4 implement a repetition algorithm when creating a game in a programming environment (Scratch)	1	7th week
	8	Project work	3.4.2.4 implement a repetition algorithm when creating a game in a programming environment (Scratch) 3.3.2.1 use instant messengers to collaborate on a project; 3.3.2.2 explain ways to exchange information on the Internet; 3.1.3.1 follow the basic rules of personal safety when working on the Internet	1	8th week

The survey results showed that most respondents expressed concern about limited access to Internet resources that would be adapted to the needs of students with disabilities. The vast majority of respondents noted the need to adjust textbooks to consider the characteristics of students with SEN. Many parents believe that the content of the digital literacy course on this web resource is not informative and does not meet the needs of students with SEN. A significant number of parents expressed dissatisfaction with the conditions in which their students receive education, highlighting the lack of adaptation and support. Some respondents noted that the digital literacy course does not stimulate students' interest or benefit their educational process. Many respondents expressed dissatisfaction with the methods and approaches used to teach the students. Many parents believe that the quality of teaching in the digital literacy course at the primary school level leaves much to be desired. Some parents noted that the education system does not sufficiently consider their students's characteristics and needs. Half of the respondents believe there were not enough computer programs with specialized capabilities for students. About half of the respondents expressed dissatisfaction with the Internet's availability of educational opportunities. Some parents believe teaching computer literacy is ineffective for their students. Some respondents pointed to insufficient accessibility conditions that would allow students to receive educational services equally with others.

The results show that the educational system has several serious problems and disadvantages related to the education of students with SEN. These problems include a lack of resources using technology and limited access to educational opportunities.

Thus, the currently used digital textbook digital literacy has been integrated with AR by projecting and introducing any virtual, imaginary objects onto real space (on the computer screen, phone, or similar device), which helps simulate complex three-dimensional shapes.

C. Formative Experiment

At the second stage of the experimental process, a formative experiment was carried out, in which training and control tests were implemented to measure the degree of mastery of educational material on digital literacy of the first section of the 3rd grade in the control group and the experimental group. The training took place in the latter using a mobile application with AR.

A mobile application with AR was developed based on the digital literacy course curriculum (see Table 2 for more details) and the digital textbook Digital Literacy. The authors of this article were the authors of the textbook.

Data from the experimental process were collected through administration data collection tools for the participants. The following statistical methods were used to analyze the data:

1) T-test to compare the means of the experimental and control groups,
2) Correlation analysis to evaluate the relationship between AR use time and total scores.

D. T-Test

Before conducting the t-test, interactive tasks with and without AR were developed. The teaching materials used by both groups were identical in content. Table 2 lists the content for the 1st quarter.

Table 2 outlines the learning goals and structure for the digital literacy course, specifically for the 3rd-grade coding subject. It presents the lesson topics, objectives, and time allocation for each week of the course. The focus is teaching students to collaborate using instant messaging, share information online, be safe online, and develop Scratch coding skills. The coding section emphasizes using repetition algorithms and loops to create basic games.

Initially, we developed content for the 1st quarter and interactive assignments with and without AR (Textbook, website). The educational materials used by both groups were identical in content. However, the difference was that the experimental group was trained using the developed digital literacy mobile application with AR components, sign language translation, voice guidance, keyboard use, text enlargement, and drawings on the screen. The control group studied using an existing digital textbook without AR components. We involved students from the following categories: students with hearing disabilities; students with mental retardation (MDD); students with musculoskeletal disorders; students with severe speech disabilities, who were evenly divided into two groups. Both educational materials were implemented within a certain period (1st quarter). Students' progress was regularly monitored, and necessary support was provided to ensure the quality of the curriculum delivery. In addition, quantitative analyses were used to compare results between groups.

Table 3 presents the test results for the experimental group that used AR and the control group that did not use AR in the course. The scores in Table 3 are based on a 100-point scale.

Fig. 3 shows a graphical representation of the test results of the students in the experimental group (who used AR) and the control group (who did not use AR). After completing the digital literacy course, the graph compares their scores on a 100-point scale. The experimental group scored significantly higher than the control group, supporting the hypothesis that AR positively impacts students' learning outcomes.

Table 3. Test results for each group

Groups	St_1	St_2	St_3	St_4	St_5	St_6	St_7	St_8	St_9	St_{10}	Mean value	σ
Experimental group with AR (after the course):	78	85	92	88	80	84	90	85	92	88	86.2	4.73
Control group without AR (after the course):	75	70	72	68	74	72	70	71	73	68	71.3	2.36

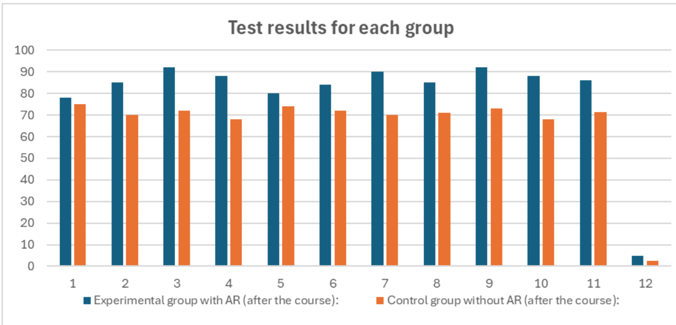


Fig. 3. Diagram of test results for each group.

Null hypothesis (H_0): The students' knowledge in both groups is, on average, the same. Alternative hypothesis (H_1): Students' knowledge in the experimental group differs from that of students in the control group.

St_1, St_2, St_3, St_4, St_5, St_6, St_7, St_8, St_9, St_{10}: students

n: number of students

$\overline{xx}$: mean value of the first group

$\overline{yy}$: mean value of the second group

σ: Standard deviation (a measure of the spread of data relative to the mean)

$\sigma_{x\text{-}y}$: Standard error of the difference of arithmetic means

n_x=10, n_y=10

P value and statistical significance:

The two-sided p-value is less than 0.0001.

By generally accepted criteria, this difference is considered highly statistically significant.

Confidence interval:

$$\overline{x} - \overline{y} = 14{,}90 \quad (1)$$

The 95% confidence interval for this difference is 11.39 to 18.41. Significance level =5% or 0.05

Intermediate values used in calculations:

$$\sigma_{x-y} = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2+\sum_{i=1}^{n}(y_i-\bar{y})^2}{n_x+n_y}\left(\frac{1}{n_x}-\frac{1}{n_y}\right)} = 1{,}672 \quad (2)$$

Calculate the criterion statistics.

$$t_{emp} = \frac{\bar{x}-\bar{y}}{\sigma_{x-y}} = 8{,}9098 \quad (3)$$

For a significance level of 0.05 and degrees of freedom k = 10 + 10 – 2 = 18, the critical value of the criterion t_{kr} (0.05, 18) = 2.1009 (taken from the 44).

Thus, $t_{emp} > t_{kr}$, i.e., 8.9098>2.1009, and at the significance level of 0.05, the alternative hypothesis H_1 is accepted; the experimental group's results are statistically significant.

Hence, we can conclude that AR in the digital literacy course significantly impacted students' learning outcomes.

E. Correlation Analysis

We used correlation analysis to compare the data obtained during the use of AR in the experimental group. To demonstrate the correlation analysis, we use data on the time spent using AR and the corresponding improvement in students' grades in the experimental group. In this way, we can explore whether there is a statistical relationship between the time spent using AR and improved learning outcomes. The results are presented in Table 4.

Table 4. AR usage results over time

Item	Value										Pearson correlation coefficient	*p*-value
AR usage time (hours)	1	2	3	4	5	6	7	8	9	10	0.996	1.63×10^{-9}
Improvement in grades (percentage increase)	5	9	12	18	20	25	29	30	34	40		

Fig. 4 shows a scatter plot illustrating the correlation between time spent on AR and the corresponding improvement in students' grades. The plot shows a positive linear relationship where the students who spent more time with AR significantly improved their grades. The Pearson correlation coefficient is close to 1, indicating a strong positive correlation and confirming that greater use of AR correlates with higher academic performance.

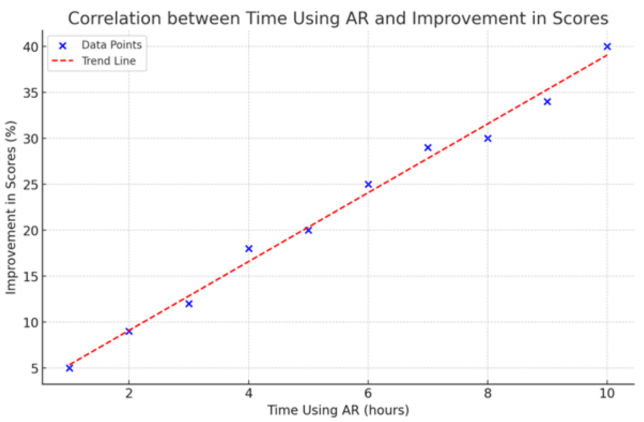


Fig. 4. Correlations between the time with AR and the score.

The provided scatter plot shows the relationship between time spent using AR and improved student grades. Each point on the graph represents a combination of the number of hours spent using AR and the corresponding percentage improvement in grades for different students or groups of students. Data explicitly show the distribution of score improvement values based on the time of AR use. Red dotted line (trend line): illustrates the overall trend, confirming a robust positive correlation between two variables. The trend line shows that as the time spent using AR increases, the improvement in scores also increases.

The study used Pearson's correlation coefficient to evaluate the relationship between these two variables. The Pearson correlation coefficient measures the degree of linear relationship between two variables and can range from −1 (perfect negative correlation) to +1 (perfect positive correlation). A value of 0 means no linear connection.

The results of the correlation analysis are shown in Table 4. The Pearson correlation coefficient is close to 1, indicating a strong positive linear relationship between AR use time and grade improvement. Students' grades improved significantly as they spent more time using AR.

The p-value is significantly less than 0.05, indicating that this correlation is statistically significant. With such a small *p*-value, we can confidently reject the null hypothesis that there is no relationship between the two variables.

Students (3rd grade) improved their perception of the digital literacy course, which may indicate the high effectiveness of visualization and interactive AR techniques for this age category.

F. Interpretation of Experimental Results

For the qualitative analysis, we collected feedback from students and teachers about their experiences using or not using AR.

1) Interview with teachers

Interviews with teachers were conducted to most effectively study the use of AR in the Digital literacy course for primary school students with SEN.

An interview toolkit was developed, and a list of open and closed questions was formulated to collect quantitative and qualitative data. Teachers with experience using AR in educational practice were selected for the survey.

With the participants' consent, interviews were recorded to ensure the accuracy of subsequent data analysis. Maintaining an open dialogue, questions were adapted depending on the answers.

These questions provide quantitative and qualitative findings about AR's impact and obtain opinions and suggestions from those directly working with this technology.

Table 5 presents the main results from the interview analysis. This methodological approach allowed us to assess AR use and identify promising directions for further research.

Table 5 summarizes the results of teacher interviews regarding their experiences with AR in the classroom. It includes details such as the years of experience with AR, the platforms used, the perceived usefulness of AR on a scale of 1–10, the improvements in student learning outcomes, the main challenges (e.g., technical issues, lack of resources), and suggestions for future developments such as the need for more intuitive interfaces and teacher training.

Table 6 presents results of a survey of students and their parents.

Table 5. Results of interviews with teachers

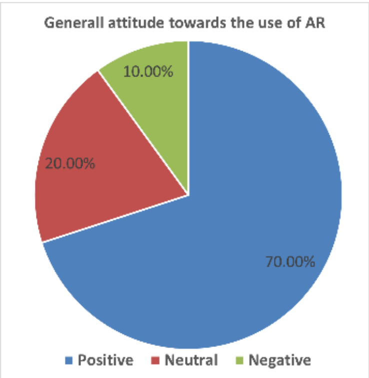
Respondent	AR experience	Platforms used	AR usefulness rating (1–10)	Improvement of educational indicators	Main difficulties	Suggestions for improvement
1	2 years	ARKit, Vuforia	8	yes	Technical difficulties	Developing more intuitive interfaces
2	3 years	ARCore, Unity AR	7	no	Lack of resources	Improving equipment availability
3	1 year	Snapchat AR	6	yes	Personnel Training	Conducting trainings for teachers

Table 6. Results of a survey of students and their parents

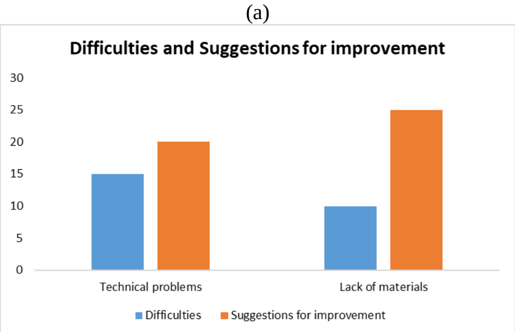
Participant	AR perception	Noticed benefits	Difficulties	Suggestions for improvement
Child 1	Positive	Helps to better understand educational material	Difficulties with the interface	Simplify program management
Parent 1	Positive	Improves engagement in the learning process	Anxiety about time in front of the screen	Limit AR use time
Child 2	Neutral	Visualizing complex concepts	Technical problems	Improve technical support
Parent 2	Positive	Increases interest in learning	Lack of training materials	Develop more educational content
Child 3	Negative	no	Distracts from studying	Make content less entertaining

2) Questionnaire of the experimental group

An experimental group of students and their parents was organized to conduct a survey to assess perceptions and attitudes toward using AR. Parents were along with their students during the interviews. The survey provided valuable feedback and an in-depth understanding of how students and their parents perceived new technologies. When selecting participants, we considered the different categories of students with special needs and the student's age. A time and place suitable for all participants was also planned. An experienced tutor was used to ensure that every student could express their opinion.



(a)



(b)

Fig. 5. Survey results: (a) Generall attitude towards the use of AR; (b) Difficulties and suggestions for improvement.

In Fig. 5(a), most respondents considered AR helpful in learning: 70% are positive, 20% are neutral, and 10% are negative. Fig. 5(b) shows challenges, including technical problems, a lack of training material, and suggestions for improvement: use better interfaces and more training materials.

Gathering feedback from students and teachers about their experiences with or without using AR in the classroom is essential for evaluating the technology's effectiveness and acceptance.

The interview questions helped to collect comprehensive information about perceptions and experiences of using AR, identifying its positive aspects and possible problems students and teachers faced.

Based on results from survey data, the following findings are found:

1) Active use of AR: Most participants (70%) used AR technologies at least sometimes, indicating a noteworthy implementation of this technology in education.
2) Improved understanding of material: 65% of respondents noted that AR helped them better understand course material, emphasizing the visualization and interactive capabilities of AR as effective learning tools.
3) Increased motivation: about 65% of students reported increased motivation when using AR, highlighting the technology's potential to increase interest and engagement in learning.
4) Technical challenges: Also, 50% of participants encountered technical problems when using AR, indicating the need for improved technical support and infrastructure.
5) Support for expanding AR: The majority of respondents (70%) favored expanding AR to use in other courses, indicating recognition of its potential and positive impact on the teaching process.

3) Explanation of the results

According to the experimental results, students lack technology-based resources and have limited educational opportunities. AR has been incorporated into the digital literacy textbook "to address the needs of students with SEN in a special presentation of material in a form that is interesting and acceptable to them.”

The results of the formative experiment suggest that using the mobile AR application in the digital literacy course positively impacted the students’ learning outcomes compared to the control group that did not use the mobile AR application.

The interpretation of the experiment results through interviews with the experimental group of students and teachers revealed positive perceptions and experiences with AR.

V. Discussion

A discussion of the results and research presented in the article on the use of AR in teaching primary school students makes it possible to evaluate the significant potential of this technology in inclusive education. The article’s authors developed a website https://specialdw-children.kaznu.kz/ and a mobile application with AR to teach the course “Digital Literacy” to students with SEN. The AR elements are integrated into the teaching content of the existing digital literacy course, which provides students with basic knowledge, skills, and abilities in computer design, presentation and processing of information, working on the Internet, computational thinking, and robotics for the effective use of modern information technologies in practice.

A. Key Points to Discuss

The effectiveness of AR in inclusive education: Fig. 6 shows an example of interaction between a mobile application and website content.

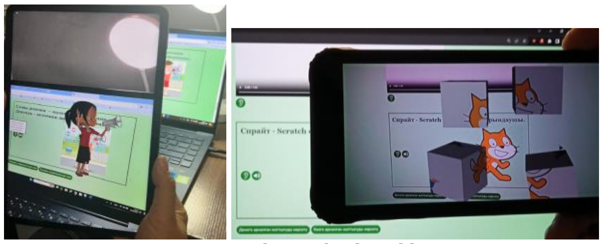


Fig. 6. An AR activity during the digital literacy course.

As an application of AR, lessons are offered that were created in the form of short video blocks for a visual representation of the learning material, definitions with drawings are highlighted when the mouse pointer is moved over them, AR opens, interactive tests and practical tasks and workbooks with touch control functions. A block diagram of how a mobile application with AR elements works can be found in Fig. 7.

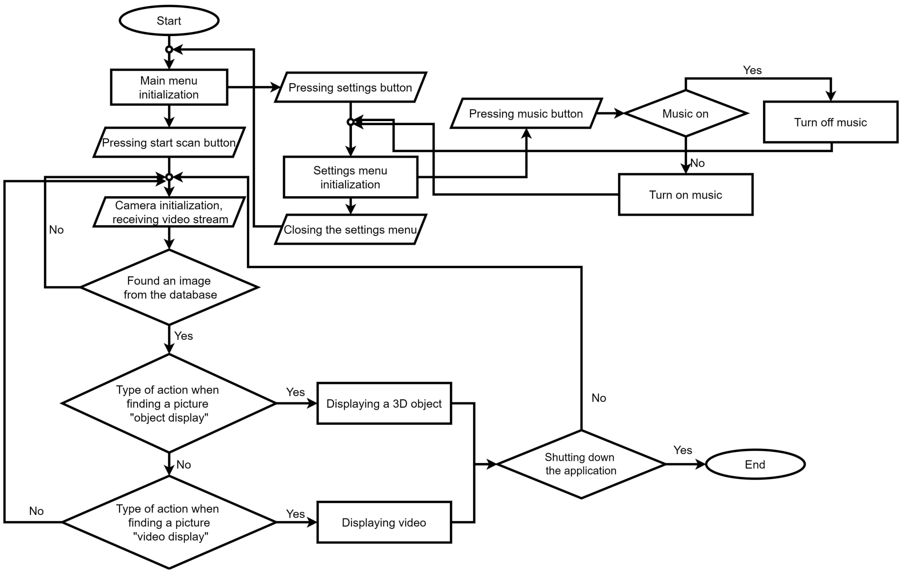


Fig. 7. Flowchart of a mobile application with AR elements.

The experimental training was analyzed using data collected from parents and teachers. The study demonstrates that AR can significantly improve students’ interaction and learning. AR provides more interactive and personalized learning experiences that enhance understanding and learning for students with diverse learning needs [29–30].

Individualization of training:

A corresponding graphic icon was installed for each group of health limitations, allowing the students to navigate through materials adapted to their abilities (Fig. 8).

Child 1 (C1): General data (Age: 10 years, Diagnosis: Sensorineural hearing loss of high degree). C1 was in a regular school with support for inclusive education. He used a hearing aid and needs services from a deaf teacher. The teacher used visual cues and adapted educational materials with subtitles and sign translation to video lessons, tests, and practical tasks in a mobile application developed and proposed by the article’s authors to improve his learning for the courses using AR. The child received information through visual resources and practical activities.

Fig. 8. Example of graphic symbols for students with different abilities.

He was comfortable completing the tasks individually as C1 feels isolated, especially in group situations with noise while using a hearing aid and without adequate support. C1 solved mathematical and logical problems in the programming section and showed above-average results.

Child 2 (C2): General data (Age: 9 years, Diagnosis: Moderate mental retardation). C2 used simple phrases to communicate and may need extra time to articulate his thoughts. Although his verbal skills were limited, he actively used nonverbal communication, such as gestures and facial expressions, to express his feelings and needs. C2 exhibited increased emotional sensitivity and reacted to stress or environmental changes more intensely than his peers. The teaching materials proposed by the authors of the article for such students are presented in small portions and gradually become more complex (Fig. 8); methods are used to facilitate complex tasks through multi-level test questions, clarity plans, graphic models, assistance in performing certain operations, examples of problem-solving. To prevent rapid fatigue, the students' attention switches from one activity to the next, and various activities are offered. Didactic material and game moments support C2's interest in the lesson and emotional mood. The website has an audio accompaniment for each definition, practical task, and test, with the option to adjust the speed and tone.

Child 3 (C3): General data (Age: 10 years, Main problem: Congenital anomalies of the spine). C3 enrolled in a comprehensive school where a program to support students with physical disabilities is available. The school had ramps, elevators, and adapted toilets so she could move freely around the building. C3 actively communicated verbally and in writing and used a virtual keyboard and two keys on a regular keyboard (1-Yes/2-No) to facilitate writing and completing the Digital literacy course assignments. C3 showed a high tolerance and a positive attitude towards the use of AR. C3 showed his passion for computer science, where he often stood out for his achievements.

Child 4 (C4): General data (Age: 10 years, Diagnosis: Severe speech impairment associated with dysarthria). C4 was a student in a class with a general education program. The school was equipped with unique technical aids to support learning. Due to his speech limitations, C4 used alternative and augmentative communication devices, such as tablet-based communicators and specialized text entry programs, to actively participate in the learning process and communicate with classmates and teachers. C4 demonstrated strong analytical skills, particularly in the area of computer science. He was proficient in logical programming and computer problem-solving, which made him an excellent student in technology subjects. In the mobile application, the tasks were ordered from simpler to more complex (Fig. 8). C4 performed the tasks more easily with the 3D images available in the mobile application.

Table 7 presents students' views on the website's educational content and mobile application.

AR technology enables the creation of customized learning environments tailored to each student's specific needs. This applies not only to physical and sensory disabilities but also to cognitive delays.

Problems and challenges: When introducing AR-based learning, students and their teachers often encounter various issues that arise during the learning process in primary school. The problem arises from the inability of teachers to develop AR learning, which affects the achievement of students' competencies. We need to consider the issues encountered in teaching specific categories of students and how to eliminate them in our research. Despite the positive aspects, using AR also brings several challenges, including training teachers, integrating existing curricula, and ensuring access to the necessary technological resources. The article notes that additional research and development could help overcome these obstacles.

Table 7. The views of students with SEN on the educational content of a website and a mobile application with AR

Educational content criterion	Views of students with special needs
Clarity and structure of the material	I understand in assimilating information, minimizing the possibility of confusion.
Interactivity	Promotes active participation, maintains attention and increases motivation.
Individual adaptation	Allows to customize the complexity and pace of the content provided, which is critical for students with different educational needs.
Visual and auditory support	Provides support through multimedia, which is important with difficulties in reading and comprehension of text.
Feedback and encouragement	Helps students understand their progress and encourages further learning through positive reinforcement.
Accessibility and ease of use	Ensures that the application can be used by students with different physical and cognitive limitations.
Content Security	Eliminates exposure to obscene or inappropriate material, creating a safe learning environment.

Social interaction and motivation: AR can help to increase student motivation and social interaction by providing platforms for communication and collaboration, which are particularly important for participants. This highlights the importance of the social aspects of learning in inclusive settings.

Practical Application: The case studies in this article show how specific AR applications improve educational outcomes. The inclusion of real-life examples makes the discussion more vivid and understandable so that educators can better understand how these technologies can be adapted to their needs.

Future of research: The article calls for further research and development of new AR-based methods and tools to support inclusive education. This emphasizes the need to continue research to improve educational outcomes for participants with disabilities.

Overall, the discussion highlights the importance of innovation in education and the ability of technologies such as AR to transform learning and make it more accessible and effective for all students.

The Digital literacy course could be taught using Google Gemini, which processes text, images, audio, and video to create different content. Its integration can enhance the educational process by offering new multimodal tools for interaction among students, maintaining their engagement and access to teaching materials. An earlier study [44] contains application examples and links to educational environments, making Gemini a promising tool for improving digital literacy.

B. Comparison of the Results with Other Studies

The results of this study are consistent with the findings of Moşteanu [1], who found that regardless of the subject area, the use of visuals, audio, and games always attracts students' attention and helps them better understand the context of the lesson. The findings from Huaman-Romani *et al.* [2] emphasize the need to adapt school curricula, especially in practical activities and with more time for feedback and assessment. The study confirms the proposal to adjust the content of educational resources for students with SEN.

Findings from earlier studies [3, 7] suggest promoting virtual reality technology in courses in more areas or disciplines. The teaching system for new technologies is constantly optimized, and vigorous development of the teaching system is encouraged to meet the needs of different students. The STUDY'S RESULTS reflect the article's assumption that more educational resources and materials should be integrated into AR to cover a broader range of topics and subjects.

Previous research [15, 16] also confirms that the presence and use of AR in inclusive education have a positive impact and are liked by students.

VI. CONCLUSION

This study examined the effectiveness of AR technologies in teaching digital literacy to primary school students with SEN.

The AR app transforms school material into 3D models, providing visual support for the subject taught, such as programming in the Scratch environment. Seeing shapes in 3D cross-sections can provide much more insight than reading a textbook on paper. AR gives the feeling that a virtual object is present in the real world, greatly aiding the learning process as it creates a more complete picture of the object. By placing the augmented information next to the corresponding object, the proposed mobile application helps to reduce the time needed to search for a description of a given object. It creates a stronger connection between object images and data.

A experiment was conducted to confirm the hypothesis that using AR to teach students can significantly improve their learning outcomes. The results of students taught with AR were compared with those trained with the traditional program. The data analysis showed that AR achieved higher results in mastering the teaching material, confirmed by a statistically significant difference between the control and experimental groups. In addition, correlation analysis revealed a positive relationship between the time of AR use and improved academic performance, indicating a high potential for integrating these technologies into courses.

In addition, qualitative methods such as interviews with teachers and parents revealed that the technology was perceived positively by teachers and students. AR helped to improve interaction between teachers and students, contributed to increased motivation, and improved understanding of the subject matter.

The study has several limitations that must be considered when interpreting its results. First, the participants were limited to primary school students with SEN, making it difficult to generalize the results to other age groups. Secondly, the study was conducted in Kazakhstan, and the results may not represent educational systems in different countries. Thirdly, using a mobile application with AR technology is limited by the technical capabilities of schools and regions. Finally, methodological limitations, such as the use of a experimental design and technical difficulties with the equipment, may also affect the validity and generalizability of the results.

It should be noted that the present study's analyses focused exclusively on students with SEN between 1st and 3rd grade. Participants gave their written informed consent to participate in this study.

To develop and improve the use of AR in education, future research is needed:

1) Researchers should examine how different age groups perceive and benefit from AR to determine which age groups respond most effectively to the technology.
2) Different AR platforms and applications must be analyzed and compared based on their effectiveness and ease of use in the learning environment.
3) Long-term studies are needed to evaluate the sustainability of improvements in learning outcomes through AR and investigate the impact on students' critical thinking and creativity development.
4) The cost-effectiveness of AR in education compared to traditional teaching methods is necessary.
5) Scholars should identify and analyze the main barriers to implementing and expanding AR use.

ETHICAL STATEMENT

The studies with human participants were reviewed and approved by Al-Farabi Kazakh National University (protocol number IRB - A510).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Lyazzat Rakhimzhanova—Data curation, Formal analysis, Funding acquisition, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing—original draft, Writing—review & editing; Darazha Issabayeva—Data curation, Formal analysis, Funding acquisition, Funding acquisition, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing—original draft, Writing—review & editing; Kulsariyeva Aktolkyn—Methodology, Resources. All authors had approved the final version.

FUNDING

This research was funded by the scientific project for grant funding of scientific and (or) scientific and technical projects for 2023–2025 of Ministry of Science and Higher Education of the Republic of Kazakhstan.

ACKNOWLEDGMENT

The article is based on the results of research obtained during scientific project for grant funding of scientific and (or) scientific and technical projects for 2023–2025 (Ministry of Science and Higher Education of the Republic of Kazakhstan, Grant No. IRN AP19678207), titled "Research and Development of software, methodological support for course "Digital Literacy" in elementary school of inclusive education using augmented reality". We express our gratitude to the MSHE RK and the leadership of the al-Farabi Kazakh National University for the opportunity to conduct scientific research.

We thank the Institute of Higher Education of the Republic of Kazakhstan and the Al-Farabi Kazakh National University leadership for the opportunity to conduct scientific research.

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