The Influence of Augmented Reality on Enhancing Literacy and Numeracy Skills in Some Selected Pre-primary Schools in Addis Ababa City Administration, Ethiopia

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Abstract: *This study was conducted to investigate the impact of Augmented Reality on children's literacy and numeracy skills in three selected pre-primary schools (i.e., Yeka-Abado, Miazia 23, and Gode pre-primary school) in Addis Ababa. A quasi-experimental design was employed, comparing a treatment group that received Augmented Reality intervention with a control group that did not receive it. The study involved 66 children, with 33 children (from 80 intervention receiving children) from the two pre-primary schools in the treatment group and 33 children from a larger population of the pre-primary schools in the control group (Gode pre-primary school). The participants were selected through simple random sampling. Data was collected using the Measuring Early Learning Quality and Outcomes instrument. Quantitative data analysis techniques such as percentage, mean, SD, and independent sample t-test were used. The major findings of the study demonstrated that the treatment group outperformed and statistically significant different from that of the control group in aggregate literacy and numeracy skills, although significant overage performances were not obtained across literacy and numeracy skills. In general, the use of Augmented Reality technology improved the complex skills (e.g. backward and forward digit span) compared to simple literacy and numeracy skills (e.g. letter identification and number comparison) of literacy and numeracy skills. Poorly designed AR (e.g. neglecting the consultation of integrated pre-primary education curriculum and the play-based learning approach in the process of AR featuring), and behavioral/structural focused of AR strategy affect the proper practice and improve literacy and numeracy skills. This raised some worries about the agency of the children, though. When integrating Augmented Reality technology, the Ethiopian integrated pre-primary education curriculum should be taken into account, and the Augmented Reality materials should be prepared considering the cultural context of Ethiopia.*

Key words: Augmented Reality, Numeracy, Literacy, MELQO, Preprimary Education Curriculum

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Introduction

Early experiences lay the groundwork for future achievement in life. Children should get comprehensive and integrated services in a range of areas during their early years, including physical development and care, language development, cognitive development, personal socio-emotional development, the arts, and creativity. These services for children must also be consistent with the methods necessary to realize children's agency. The effectiveness of the services depends on the clear knowledge of and understanding of young children's characteristics and intrinsic skills. Children are naturally inventive, creative, and they experiment, investigate, try out, and analyze things (Vretudaki & Athanasopoulou, 2025). Offering comprehensive services with the aim of achieving these learning outcomes will therefore have a significant impact on the country's developmental spectrum, including increasing enrollment, ensuring equity, lowering absenteeism and dropout rates, improving the quality of education and academic achievement in later school years, and offering a high return on investment (MoE, 2021).

A pedagogy that supports and encourages the role to transfer of ownership and responsibility from adults to children, as well as the development of self-efficacy and internal locus of control is essential (Belay & Daniel, 2022; Yigzaw et al., 2022; Belay et al., 2022). Thinking deeply on the process to make children intentional learners and practice intentional teaching (Yigzaw et al., 2020), use of play based approach (both free play and guided play) and other strategies are suggested to use in pre-primary education (MoE, 2021). Further, children naturally use their senses to understand the world which contributes to foster holistic skills (Akman et al., 2003; Eshach & Fried, 2005; UyanıkBalat, 2010; Trundle & Saçkes, 2012), and requires to deliver different simulations and experiences so as to ignite children’s fastest brain development and intense synaptic entanglements.

One of the methods which is claimed to be useful to cultivate children's agency is Augmented Reality (AR). Although Augmented Reality's historical profile and landscape of application in pre-primary education are low (Masmuzidin & Aziz, 2018; Madanipour & Cohrssen, 2021), it is one of the new technologies with excellent reflection in the field of education (Cabero-Almenara & Roig-Vila, 2019; Jaiswal et al., 2021) and pedagogical tools that have a pervasive role in the process of learning. According to Uur and Apaydn (2014), augmented reality is defined as the use of technology to simulate the real-world environment through computer-generated text, audio, video, and images in a virtual setting. Additionally, the implementation of AR necessitates re-organizing the learning environment in the classroom to incorporate teamwork, individual child pace, and assessment of improvements that can aid for children's learning (Cascalesa et al., 2012). In addition, using technology improves children' focus and attentiveness on their tasks (Hassan et al., 2021). Even though there aren't many AR practices in preprimary education, the technology is recommended as an additional pedagogy because it can engage children's senses, capture their attention, and create a fun environment (Kuzgun, 2019). The use of the application in education has gained popularity and it has been linked to improved learning outcomes across a variety of academic disciplines (Hossain & Ahmed, 2021), permits the use of 3D objects, texts, photos, videos, and animations to be used simultaneously (Wang et al., 2021) as well as devices such as desktops, laptops, portable devices, and smartphones (Kirner et al., 2012).

Furthermore, different studies magnify the benefits associated with AR for children's education like providing an interactive and immersive learning environment that captivates young learners' attention, facilitating active participation and engagement (Dunleavy et al., 2009), allows children to manipulate virtual objects, fostering kinesthetic learning and enhancing their understanding of abstract concepts (FitzGerald & Ishii, 2018). Besides, Düzyol et al. (2022) found that AR effectively draws children's attention and heightens their sense of authenticity. Further, Masmuzidin and Aziz (2018) observed that AR increases motivation in preschool education, while Saez-Lopez and Cozar-Gutierrez (2020) found that AR enables a wide range of interactive experiences in the classroom. Moreover, AR has been found to engage children's attention and foster a sense of reality, peer relationships, and a fun learning environment (Hassan et al., 2021; Kuzgun, 2019). It is also stated that AR is responsible to instill children’s concentration, vocabulary enrichment, reading, and creativity (Kelpsienė, 2020) as well as it accelerates the memorization of materials, enhances children's interest, and improves their self-efficacy in learning (Piatykop et al., 2022).

Similarly, it promotes effective communication and interactions among teachers, students, and families (Cascalesa et al., 2012) while simultaneously increasing motivation, concentration, and learning outcomes (Sobral & Menezes, 2012). AR expands children's vocabulary (Santos et al., 2016) and improves their understanding of concepts (Hassan et al., 2021). Teachers can also utilize AR to create efficient and engaging learning environments (Chen et al., 2007) that are comfortable, innovative, and foster creativity (Rasalingam et al., 2014). Moreover, it promotes collaborative learning (Kritzenberger, 2002), ignites language pronunciation and memorization (Chen et al., 2007), and offers new forms of interaction, collaborative opportunities, and increased motivation to learn (Sampaio & Almeida, 2018). Besides, studies have shown that teachers trained in AR are better at integrating and implementing science activities (Kahriman et al., 2020), utilize AR games to teach children abstract ideas like color mixing, mathematical expressions, and recognizing 2D and 3D geometric forms (Zhu et al., 2017). Furthermore, AR has shown promise in aiding adult students in solving mathematical problems (Cacciatore, 2018), and allowing children to learn while enjoying themselves and supporting their learning environment (Ylmaz et al., 2017) as well as improving middle school students' math problem-solving abilities (Kelpsiene, 2020).

Despite the advantages of AR in education, there are very few studies exploring its use in early childhood education or learning alphabets and word building (Safar et al., 2016). In the literature, some researchers have drawn attention to limitations associated with AR. For instance, Lin et al. (2015) stated that students find AR complicated, and that they often encounter technical problems while using it. Without a well-designed interface and guidance for the students, AR technology can be too complicated for them to use (Squire & Jan, 2007). The various devices that deliver AR applications may cause additional technical problems (Wu et al., 2013). Additionally, Kim et al. (2018) stated that bulky AR technologies such as HMDs are not easy to handle, and that AR technologies should be developed to be smaller, lighter, more portable, and fast enough to display graphics. Aside from technical limitations, Munoz-Cristobal et al. (2018) showed that excessive additional lecture time is required to use AR effectively in education. In the case of pre-primary schools with large classes, there are issues with the way the physical classroom setup, organization of the AR, and the interface between these two are fundamental issues (Kuzgun, 2019). Many studies in Ethiopia showed that children are struggling with literacy and numeracy skills that are important for their future learning (UNESCO et al., 2017). One of the reasons mentioned in these studies including outdated teaching pedagogies, lack of engaging learning approaches and the capacity of teachers. These challenges are particularly concerning in the context of the Sustainable Development Goals (SDGs), especially SDG 4, which aims to *ensure inclusive and equitable quality education and promote lifelong learning opportunities for all*. Ethiopia's progress toward this goal is hindered by the persistent quality gap in early childhood education. While efforts have been made to improve access, there is a significant gap in the implementation of modern teaching tools and technology-assisted learning methods, such as AR, that have been proven to enhance learning outcomes globally. AR practice seems to realize the focus of the current Ethiopian education and training policy. The education and training policy explicitly state that pre-primary education should make use of appropriate technology in its program (MoE, 2023) as well as the Ethiopian pre-primary teacher training system offers a course on ICT for pre-primary teacher education for both certificate and diploma program (MoE, 2023). Particularly, the ICT course syllabus should integrate the AR design, activities, and application in pre-primary education setting. Therefore, it is necessary to carry out research in Ethiopia that looks at how augmented reality could improve early learning outcomes with a particular to literacy and numeracy skills. As educational requirements change, it is more crucial than ever for pre-primary education to include instructional technology. To better understand how this technology can enhance children's educational and holistic development, this study looks at how Augmented Reality can improve the learning outcomes of the literacy and numeracy skills for pre-primary school children by comparing with those children who were not exposed to AR application.

Objectives

The main aim of the research is to compare the literacy skills of children who have learned through Augment Reality with that of those who haven't; and to examine the numeracy skills of children who have learned through Augment Reality with that of those who haven't.

Methodology

Study Area and Design

The study was conducted in Addis Ababa city administration, specifically in three government pre-primary schools, Yeka-Abado, Miazia 23, and Gode Pre-Primary School. Yeka-Abado and Miazia 23 Pre-primary schools served as the treatment groups for the study, while Gode Pre-primary school, which had standards for teaching and learning that were the closest to the Yeka-Abado Pre-primary schools, served as the control group. The treatment schools received fixed

11MPs broadband internet connectivity. Additionally, teachers in the treatment group had access to a range of workshops and materials. The AR intervention work was scheduled for 10 of the 80 class times. The comparison group consisted of the entire class of 277 children from Gode pre-primary school. A quasi-experimental research was applied in this study. The participants were grouped into treatment and control groups. The children who had received AR teaching aid are called the treatment group and those who hadn't are named as the control group. Details for the intervention conditions are stated below.

Intervention Activity

In order to investigate the efficacy of AR applications in pre-primary education learning outcomes, the Plan International Organization launched a project in Ethiopia. The AR applications were created to improve a variety of learning skills, including phonics, math, reading, and writing. Reading skills include letter and word recognition, comprehension of words and ideas, reading speed and fluency, vocabulary development, and number identification, measurement, and science concepts. Writing skills include neatness, consistency, accurate letter and word reproduction, spelling, and organization. To adopt AR technology, resources like smart phones or tablets, an AR guidebook, training for teachers and supervisors, as well as woreda and ICT experts, have been provided. To prevent children from becoming addicted to technology and give them more time to practice other practical activities, two days a week were set aside for AR practice.

The intervention involved AR in Ethiopian pre-primary schools. The integration of these technologies into educational activities included literacy and numeracy skills. Initially, all required AR tools were purchased and AR technology prepared, curricular content was installed in the AR as well as AR guidebook was prepared. In the AR application, A-Z alphabets, A-Z writing activities, patterns, images, puzzles, numbers, and science concepts were installed. The pre-primary education curriculum (2014 E.C) was the base for preparing the AR application. Teachers, pre-primary school coordinators, special needs experts, ICT professionals, and Addis Ababa Woreda experts or supervisors received training on how to utilize the prepared AR for literacy and numeracy skills, covering AR topics, relevance of AR, and other pertinent materials.

Finally, the intervention was implemented in Yeka-Abado and Miazia 23 pre-primary schools in Addis Ababa city administration with the support and training provided by Plan International Ethiopia. The teachers and staff received the necessary training to effectively integrate the AR developed into their teaching methodologies. Two days were allotted for AR learning from the five days of the academic calendar per week. Teachers tried to plan what to do, how to do, and with whom to do in the process of AR application. The usual schedule (based on the lesson plan for a week) was used to teach children for the remaining three days. Ongoing discussions and evaluation (organized in the progress AR report) were carried out to examine the effective implementations of the AR application. There were mechanisms to mitigate the identified problems. The intervention was carried out for one year (the actual intervention). Seven months were used to prepare the AR application, assessment, and training, and purchase the materials). Research was conducted to assess the effectiveness of the AR and 3D visualization intervention. This research aimed at evaluating the influence of these technologies on literacy and numeracy skills of pre-primary school children.

Samples and Sampling Techniques

The study participants were from the treatment and control groups of the pre-primary schools. In this study, a total of 66 children at the age of five and six years old from Yeka-Abado, Miazia 23, and Gode preprimary school were involved. It is stated that 80 children from Yeka-

Abado (40) and Miazia 23 (40) had received the AR intervention. Therefore, representative samples of 33 children who took the AR intervention were selected randomly from Yeka-Abado (16) and Miazia 23 (17). It is not possible to take the entire classes because of feasibility and practicability and due to time and resource constrains. To ensure the representatives of the samples the researchers used random selection and sample size considerations. Gode, which was designated as the control group, had 33 children sampled from a much larger population of 277 (11.9%).

Children's Demographic Characteristics

Participants were selected from two sections of the preschools, including 5 years and 6 years old classrooms. Some significant variations is seen in the demographic distribution of preschool-aged children (ages 4-6) in the treatment and control groups. Although there are 33 children in each group, there are some minor differences in their ages. Three 4-year old, sixteen 5-year-old, and fourteen 6-year old and older make up the treatment group. On the other hand, the control group consists of one 4-year-old, fifteen 5-year-old, and seventeen 6-year-old and older. This suggests that there are somewhat older children in the control group, which might affect developmental comparisons. With respect to gender distributions, there are 11 boys and 22 girls in the treatment group and 19 boys and 14 girls in the control group. The larger proportion of females in the treatment group results in more girls being included in the study, while the control group has slightly more boys than girls, following a simple random sampling system.

Instruments

Questionnaires as instruments were used to realize the impact of the intervention project. For a survey questionnaire**,** the Measuring Early Learning Quality and Outcomes (MELQO) are used to investigate the role of AR in children literacy and numeracy skills. In low- and middle-income nations, the use of MELQO is doable in the study (UNESCO et al., 2017). AR study was not the first one to test the MELQO measure. The MELQO has been modified by many scholars to fit the Ethiopian environment. Both the local context and Ethiopian norms were sought to be adhered to. To ensure the measure's viability in terms of employing a reliable instrument, the researchers tried to see if the instruments matched policy texts and cultural realities. The study on early learning in Ethiopia also made use of MELQO: Early Learning Partnership Ethiopia Phase 1 and 2 reports on the impact of pre-primary education on school readiness. The World Bank and the UK Foreign, Commonwealth, and Development Office (FCDO) also provided funding for the study. The study was carried out in Addis Ababa, Amhara, Benshangul and Gumuz, Oromia, SNNP, and Somali, among other regions of Ethiopia. The instrument was made available in these areas' native language. In the research, efforts were undertaken to assure its validity and contextual concerns (Kim et al., 2022). Some studies have examined the issues of early childhood education in Ethiopia by using MELQO measure, for example, first national assessment of pre-primary education (Hagos & Mulugeta, 2021); assessment of the status of O-Class in four Regional States (Teferra & Hagos, 2016); measuring quality of pre-primary education (Raikes et al., 2020); and equitable access and learning in early learning (Rossiter et al., 2018). Table 3 provides more specific information on MELQO. To adapt this MELQO tool, it has gone through various stages. These include: (1) a review of current early childhood education policy papers; (2) a stakeholder workshop with central and regional government officials, NGOs, researchers, and other early childhood education stakeholders to create a draft version of MELQO Ethiopia; and (3) a review of early childhood education policy documents.

Table 1: Global MELQO modules

Module	Instruments	Core items
Measure of Development and Early Learning (MODEL)	Direct child observation, and parent or teacher survey	The MODEL incorporates globally comparable elements in various areas, including early numeracy skills, early literacy skills, executive function, social-emotional development, and gross/fine motor skills. Additionally, it encompasses items that assess children's home and family environments.

Source: UNESCO et al. (2017)

Ethiopia's Components of MELQO

Early learning-related items that are globally comparable are included in the MODEL child-direct assessment in the areas of early reading, early numeracy, executive function, fine motor abilities, and socio-emotional development. Overall, the measure looks at concepts connected to school readiness, or the collection of core abilities and skills that help children succeed in school. The government-prepared national curriculum syllabus for O-Class in Ethiopia and the domains of the MODEL child-direct assessment line up quite well (MoE, 2014). Out of the MELQO measure, pattern was included. The items were developed from rational, Ethiopian integrated pre-primary education curriculum (2021) and literatures in early childhood education.

Table 2: Ethiopia's components of MELQO

Module Domain/Ethiopian O-class curriculum		Module assessment tasks	Skills targeted
Global proficiency in line with Ethiopian curriculum	Specific competence aligned with Ethiopian curriculum		
Early numeracy/ development of basic computational skill	Number concepts (identify and count numbers)	Verbal counting	Knowledge of counting numbers in order orally
		Producing a set	Knowledge of word order, one-to-one correspondence, and cardinal value
		Number identification	Ability to name numerals (number symbols)
		Number comparison	Ability to compare number magnitudes and receptive language in measurement vocabulary
		Simple addition and subtraction	Addition and subtraction skills

	Measurement skills (understand the relationship between things; describe the concept of space)	Receptive spatial vocabulary	Receptive language skills in spatial vocabulary (e.g., “on”, “under”, “in front of”, and “next to”
		Mental transformation	Spatial skills used to transform two shapes into one shape
Early literacy/ language development and utilization	Speaking (develop communication skills; growth of body parts and sense organs)	Expressive language	Verbal naming/differentiation of names of body parts
		Expressive vocabulary	Verbal naming by category (nutritious foods, animals)
	Pre-reading skills/alphabet knowledge	Letter identification	Letter name identification/knowledge
		Letter sounds identification	Identification of sound in a letter
		Letter sounds discrimination	Discrimination of sound in a latter
	Receptive Language	Listening Comprehension	Listening Comprehension
	Pre-writing Skills	Name writing	Name writing
Executive Function	Working memory and inhibitory control	Head-toes	Ability to inhibit a normal response and implement a new learned response
		Backward digit span	Ability to recite digit sequence backward
	Short-term memory	Forward digit span	Ability to recite digit sequence from memory
Fine motor skills/ Development creativity and appreciation	Fine motor skills	Shape copying	Copying shapes (X, circle, and rectangle) from model drawings of those shapes
Socio-emotional skills/ Individual, social and emotional development	Relating to oneself (develop self-expression and self-help skill)	Self-regulation	Ability to control emotions and social behavior in the interest of engagement and participation in both social interactions and independent work
	Relating to others	Social cognition	Ability to read others’ emotions and respond appropriately, as well as prosocial behavior that includes helping others who may be in distress
		Social competence	Ability to coexist and interact with others in a competent manner, essentially getting along with other children and adults
		Emotional well-being	Aspects of optimal mental health that could predict more serious mental health problems

Source: The Ethiopian '0' preschool curriculum (MoE, 2014) is matched with the MELQO assessment (UNESCO et al., 2017).

Segments of early literacy skills measured using questionnaire was comprised of letter identification (16 items), expressive language (5 items), phonological awareness (5 items), tracing letter (4) and words (2), expressive vocabulary (2), and receptive special vocabulary (5 items). Besides, children’s expressive vocabulary skills were measured using open ended questionnaire. Children were invited to participate by providing their answers to the following prompts: "Please list as many things that you can eat as possible (Verbal Naming by Nutrition Food)" and "Kindly share the names of all the animals you know (Verbal Naming by Animals)." The MELQO program encourages the child to provide ten responses for each prompt, as per their intentions and instructions.

In addition, early numeracy skills are measured using number identification (10 items), number comparison (3 items), mental transformation (3), forward counting (5 items), backward counting (5 items), matching picture (6 items), pattern (3 items) and shape copying skills (4 items). For all items, correct (1), incorrect (0) and I don't know (2) options are provided.

Validity and Reliability of the Instruments

The reliability of the instruments was checked using Cronbach alpha. The reliability values using Cronbach's alpha are 0.801 for literacy skills and 0.701 for numeracy skills. Content validity provides evidence about the degree to which elements of an assessment instrument are relevant to and representative of the targeted construct for a particular assessment purpose. Experts (researchers, Plan International Ethiopia Staff and AR designer) reviewed the instrument for content validity. Specific guidelines, used for selection and inclusion of the experts included: Experienced academicians and familiarity with the thematic domains/concept in evidence-based practice (teaches, practices, or publishes peer-reviewed papers in the field of AR in preschool education). The instruments were self-distributed to each reviewer. The experts were also requested to identify deficient areas and provide recommendations or suggestions on ways to improve the sentence structure to ensure clarity and conciseness. Then the reviewers reflected on the instrument and returned it to the principal investigator with constructive comments. Therefore, high proportion of items on the instrument achieved a relevant rating by the content experts. Several editorial corrections were also made in the process, including language consistency and clarity.

Procedure of Data Collection

Consent letters to conduct the research were provided to the three pre-primary schools before implementing the research. After getting the appropriate consent to conduct the study, different steps were carried out to execute the data collection procedures of the study. Information about the population of the children, number of teachers, assistant teachers, and directors were collected from the two (treatment group and control group) schools. Before the data collection team travelled to the research sites, the necessary preparations had been made by the core researcher team members. The preparations included finalizing data collection instruments, organizing logistics necessary to travel to the three preschools, securing support letters from Addis Ababa City Administration Education Office, searching for and recruiting qualified and experienced data collectors who were well acquainted with the local context of the study. In all the three schools, prior communication had been made with relevant government offices particularly, Addis Ababa Bureau of Education to obtain their support during the field data collection process. Accordingly, the field data collection teams enjoyed extended support of government offices. The first field workday was devoted to training data collectors on the data collection instruments, orienting them about the objectives of the study and PIE's child protection policies, ethical considerations, and standards to be followed before-during- and after the sessions with participants. In collaboration with offices of Addis Ababa Bureau of Education, gate keepers were identified and contacted to guide the field data collection team at each of the study sites.

Data Analysis

Independent samples t-test (to compare the result of control and treatment groups), mean, and SD were used to compare the mean values attained in literacy and numeracy skills for both groups. This supports to understand in which item or items have exceeded one group compared to the other. The IBM SPPS statistics 25 was used to analyze the data. The assumptions of parametric tests including continuous variables, normal distribution, and **homoscedasticity** of the data were checked and fulfilled before staring the analysis.

Ethical Considerations

The study complied with Plan International Child Protection Policy, Research Policy & Standards, and Guideline for Consulting with Children & Young People with Disabilities. The rights and dignity of study participants were fully respected and protected by applying all required research ethics including securing consent from each participant child parents. Signed consents were secured from many of the participants' children parents. When signed consents were not possible, recorded oral consents were secured. All field staff members signed Plan International Child Rights Protection Policy Acknowledgement Form. We ensured confidentiality, voluntary participation, safeguarding, cultural sensitivity, child assent, and debriefing.

Results

The key results on early literacy and numeracy are covered in this part.

Descriptive Statistics of Treatment and Control Groups on Early Literacy and Numeracy Skills

The table below compares the average performance of children who received AR support with those who did not. The treatment group performed better in aggregate literacy (84% vs. 68%) and numeracy skills (71% vs. 58%) than the control group. For the sub-skills of literacy, except for slightly higher average performance in expressive language (98% vs. 100%) and tracing letters (92% vs. 99%) in the control group, the AR-supported group outperformed in various literacy skills. These included tracing words (88% vs. 55%), letter identification (93% vs. 91%), phonological awareness (55% vs. 54%), special vocabulary (67% vs. 57%), verbal naming of nutrition (73% vs. 45%), and verbal naming of animals (77% vs. 46%) compared to the control group. Furthermore, the treatment group had higher average performance in number comparison (82% vs. 79%), forward counting (77% vs. 46%), backward counting (44% vs. 26%), drawing shapes (95% vs. 67%), and pattern making (55% vs. 11%) than the control group. However, the control group performed better in number identification (89% vs. 98%), matching items (98% vs. 99%), and mental transformation (29% vs. 34%) compared to the treatment group. The study suggests that AR's interactive and visual support for complex tasks such as forward and backward counting and pattern making may have contributed to the treatment group's better performance. However, concerns remain regarding lower performance in certain literacy and numeracy skills, such as number identification.

Table 3: Descriptive statistics of treatment and control groups on early literacy and numeracy skills

	Variables	Groups	
		Treatment	Control
Early Literacy Skills	Expressive language	98%	100%
	Tracing Letters	92.4%	99%
	Tracing words	88%	55%
	Letter identification	93%	91%
	Phonological Awareness	55%	54%
	Special Vocabulary	67%	57%
	Verbal Naming for nutrition	73%	45%

	Verbal Naming for Animals	77%	46%
Early Numeracy Skills	Number identification	89%	98%
	Number comparison	82%	79%
	Forward counting	77%	46%
	Backward counting	44%	26%
	Drawing shapes	95%	67%
	Pattern making	55%	11%
	Matching Items	98%	99%
	Mental Transformation	29%	34%
Aggregate Literacy and Numeracy Result	Literacy	84.43%	68.38%
	Numeracy	71.13%	57.50%

Composite Independent Sample t-test Result on Augmented Reality Supported Learning on Children's Literacy and Numeracy Skills

As the table below shows, the mean scores of aggregate literacy (treatment mean: 19.90, SD: 2.027; control mean: 13.67, SD: 2.027; t = 8.379, df = 64, p = 0.000) and numeracy skills (treatment mean: 5.68, SD: .742; control mean: 4.61, SD: .593; t = 6.49, df = 64, p = 0.000) were higher in the AR-supported treatment group and showed a statistically significant difference compared to the control group. This result suggests that embedding AR in early childhood education enhances children's performance in literacy and numeracy skills.

Table 4: Independent sample t-test result: AR supported learning on children's literacy and numeracy skills

Variable	Group	Mean	SD	T	df	Sig. (2tailed)
Literacy Aggregate	Treatment	19.90	2.027	8.379	64	.000
	Control	13.67	3.357			
Numeracy Aggregate	Treatment	5.6783	.74200	6.493	64	.000
	Control	4.6051	.59249			

Early Numeracy Skills

In this section, different numeracy skills were measured. In the table above, the mean score for the treatment group in aggregate early numeracy skills was higher, and a statistically significant result was obtained. This section compares the two groups on sub-topics of numeracy, such as number comparison, number identification, mental transformation, drawing shapes, forward digit span, matching items, backward digit span, and pattern skills.

Table 5: Independent sample t-test results on early numeracy skills

Variable	Group	Mean	SD	T	Df	Sig. (2tailed)
Number Comparison	Treatment	0.82	0.27	0.403	64	0.689
	Control	0.79	0.34			
Number Identification	Treatment	0.89	0.23	-2.35	64	0.022
	Control	0.98	0.05			
Mental Transformation	Treatment	0.29	0.22	-0.923	64	0.36
	Control	0.34	0.23			
Drawing Shape	Treatment	.95	0.12	6.77	64	.000
	Control	0.67	0.20			
Forward digit span	Treatment	0.77	0.37	5.57	64	0.000
	Control	0.46	0.33			
Matching pictures	Treatment	0.98	0.06	-1.194	64	0.237
	Control	0.99	0.04			
Backward Digit Span	Treatment	0.44	0.37	2.617	64	0.011
	Control	0.26	0.19			
Pattern (single-double patterns)	Treatment	0.55	0.38	6.051	64	0.000
	Control	0.11	0.16			

Children's Number Comparison Skills

The researchers measured the mean values of the responses to assess the average performance of each group. Number comparisons between the treatment and control groups were computed. Children had been told to state that this number is greater than the alternative. The question of which number is larger 3 or 5, 8 or 6, 4 or 7 was posed. Overall, the difference was not statistically significant difference in the mean scores between the two groups (treatment mean: 0.82, SD: 0.34; control mean: 0.79, SD: 0.27; $t = 0.403$, $df = 64$, $p = 0.689$).

Children's Number Identification Skills

The researchers analyzed the children's number identification skills. Children were requested to recognize the list of numbers. The correct identification of numbers like 2, 7, 9, 8, 5, 13, 17, 12, 14, and 20 was asked. The control group's mean was discovered to be greater than the treatment group as a result. The AR intervention had no discernible positive impact on the identification of numbers in this regard. Though the mean difference for the control was slightly greater for the treatment, the AR application did not increase the chances for children to learn numbers easily. This difference was found to be statistically significant based on the independent sample t-test result (treatment mean: 0.89, SD: 0.23; control mean: 0.98, SD: 0.05; $t = -2.35$, $df = 64$, $p = 0.022$).

Children's Mental Transformation Skills

Regarding mental transformation, both the treatment and control groups performed below average. Children (from the two groups) were given different figures and asked various questions, such as which figure would fit if we put the two pieces together from the given figures, which figure is the right fit if we put the two separate pieces together from the given set of figures, and which figure is the appropriate fit when we put the two pieces together from the four figures. On average, the treatment group and the control groups achieved mean values of 0.29 and 0.34 respectively indicating below-average performance. The independent sample t-test also did not find a statistically significant difference between the two groups (treatment mean: 0.29, SD: 0.22; control mean: 0.34, SD: 0.23, t = -0.923, df = 64, p = 0.36).

Children's Drawing Shape Skills

In this study, participants were tasked with shape copying (write the provided shapes), specifically drawing a cross, circle, rectangle, and triangle. Overall, the treatment group had a higher average mean value compared to the control group and this difference was found to be statistically different as the t-test result revealed (treatment mean: .95, SD: .12; control mean: .67, SD: .20; t=6.765, df=64, p=.000). This suggesting that the treatment had a positive impact on participants' ability to accurately copy shapes. This may be attributed to AR platforms that create the opportunities for children to practice drawing on them.

Children's Forward Digit Span Skills

The research finding compared the performance of children who received Augmented Reality (AR) (treatment group) with those who did not receive AR (control group) in their forward digit span skills. The items include 1... 6, 5... 2... 8, 3... 5... 4, 8... 3... 1... 4, and 1... 2... 4... 7... 3, treatment and control groups are instructed to count forward for the specified items. For the purpose of not counting the next number, it was not accepted as correct if one digit was missed. The findings suggest that the treatment group performed above average, with high accuracy, while the control group performed below average, indicating lower working memory capacity. These differences were confirmed by an independent sample t-test, which showed that the disparity between the two groups was statistically significant in forward digit span (treatment mean: 0.77, SD: 0.26; control mean: 0.46, SD: 0.18; t=5.573, df=64, p=0.000).

Children's Matching Pictures Skills

The study assessed the performance of both groups in matching pictures based on given criteria. Both groups were provided with matching a picture to a similar image. There are shown double and mixed images with triangle, square, rectangle, oval, circle, and star. The difference was not statistically significant in matching pictures, as revealed by the independent sample t-test (treatment mean: 0.98, SD: 0.061; control mean: 1, SD: 0.000; t=-1.194, df=64, p=0.237).

Children's Backward Digit Span Skills

Furthermore, the study revealed interesting findings for multiple items. Items were given to the children so they could count backward. The backward digit numbers include 4... 1, 2... 8... 8, 3... 1... 7, 4... 8... 2, and 8... 3... 6... 1... 5 asked the children to properly count. Thus, independent sample t-test showed that the average mean score for the treatment group was higher and statistically significant in backward digit span compared to the control group (treatment mean: 0.44, SD: 0.37; control mean: 0.26, SD: 0.19; t=2.617, df=64, p=0.011).

Children's Pattern Skills

The study also examined three different patterns (single-single, double-double, and single-double pattern). The missed single pattern (A B A B A B, A B A B___), double pattern (AA BB AA BB, AA BB AA___), and single-double pattern (C DD C DD C, DD C____) were given to the children to complete. As a result, the treatment group had average mean values of 0.55 for the single pattern, 0.60 for the double pattern, and 0.48 for the single-double pattern. The control group had mean values of 0.11 for the single pattern and 0 for both the double and single-double patterns. Thus, the mean value for the treatment group was found to be high compared to the control group and independent sample t-test also indicated a statistically significant difference between the two groups in children's pattern skills (treatment mean: 0.55, SD: 0.38; control mean: 0.11, SD: 0.16; t=6.055, df=64, p=0.000).

Generally, the Augmented Reality (AR) intervention seems to have improved children's numeracy skills, including forward digit span skills, number identification, pattern recognition skills, and even backward digit span skills. The overall findings demonstrate the potential for AR to significantly influence on cognitive abilities, even though the impact on picture-matching, number comparison, and mental transformation abilities were not very significant. Particularly, AR creates opportunities for children to practice patterns, puzzles, and practical exercises.

Children Early Literacy Skills

This section is intended to illustrate the independent sample t-test results for the two groups on sub-topics of literacy skills. According to Table 6, the mean score for aggregate literacy skills was higher for the treatment group, with a statistically significant difference.

Table 6: Independent sample t-test results on early literacy skills

Variable	Group	Mean	SD	T	df	Sig. (2tailed)
Expressive language	Treatment	0.98	0.11	-1.277	64	.206
	Control	1	0			
Letters Tracing	Treatment	0.92	0.22	-1.74	64	0.087
	Control	0.99	0.04			
Word Tracing	Treatment	0.879	0.33	3.904	64	0.000
	Control	0.55	0.36			
Letter identification	Treatment	0.93	0.22	.549	64	0.585
	Control	0.91	0.08			
Phonological Awareness	Treatment	0.55	0.30	.164	64	0.871
	Control	0.54	0.30			
Special Vocabulary	Treatment	0.67	0.45	1.386	64	0.171
	Control	0.57	0.49			
Verbal Naming for nutrition	Treatment	7.27	1.18	7.552	64	.000
	Control	4.52	1.73			
Verbal Naming for Animals	Treatment	7.70	1.21	6.367	64	.000
	Control	4.61	2.51			

Speaking Skills

In this section, the communication skills of children are measured and presented.

Children's Expressive Language

Given a specific task participants were asked to identify the names of various body parts. The two groups were asked to name the body parts. Tell me the name of this body part by pointing to the eye, tooth, fingers, and knee, among other inquiries posed. The scores in this study suggest that participants in both groups had a high level of expressive language skills in identifying body parts, as their scores were close to the mean value of 1. Therefore, it can be concluded that the participants' expressive language abilities in this task were above average, and the mean difference between the treatment and control groups in expressive language was not found to be statistically significant (Treatment mean =.98, SD=.11; Control mean=1, SD=0; t=-1.28,df=64, p=.206).

Pre-writing Skills

Children's Letter Tracing Skills

In this study, the result of tracing letters for the two groups is presented. The two groups were also asked to trace different letters like A, M, K, and W and the difference was not found to be statistically significant (treatment mean:.92, SD:.22; control mean:.99, SD:.04; t=-1.74, df=64, p=.086).

Children's Word Tracing Skills

The children were informed to write or trace words like "Cat" and "Dog" items. The results showed that the treatment group had a higher average mean compared to the control group. Overall, the result indicates that the treatment group exhibited above-average performance in the tracing word task compared to the control group. This difference was statistically significant difference as the independent sample t-test uncovered (treatment mean: .88, SD: .33; control mean: .55, SD: .36; t=3.904, df=64, p=.000).

Children's Pre-Reading Skills

Children's Letter Identification

The letter identification results for both the treatment and control groups were computed. The letters such as B, D, F, A. C, K, M, S, N, Q, and G were asked to identify and the difference was not statistically significant (treatment mean: .93, SD: .22; control mean: .91, SD:.08; t=.549, df=64, p=.585).

Children's Phonological Awareness Skills

The groups were given a quiz to understand children's phonological awareness of various concepts, such as which word starts with a particular sound: Tea, breakfast, bread, as well as a cat, a ball, and care as example and the difference was not found to be statistically different (treatment mean: .55, SD: .30; control mean:.54, SD:.30; t=.164, df=64, p=.871).

Children's Receptive Special Vocabulary Skills

When compared to children who had received additional instructional resources like augmented reality and 3D visualization on receptive special vocabulary, the results of children's ability to correctly identify the images of the ball on top of the box, underneath the box, in front of the box, next to the box, and inside the box did not show statistically significant difference (treatment mean: .67, SD: .45; control mean:.57, SD:.49; t=1.386, df=64, p=.171)

Children's Expressive Vocabulary Skills

The treatment and control groups were asked to enumerate or express verbally the names of the nutritious foods they are familiar with. Children who received AR intervention produced more nutritious foods lists than their control counterparts. Children were also asked to list the names of any familiar animals. Regarding verbally expressing the names of the animals they are familiar with, the treatment group fared better. Thus, there was a statistically significant difference between the treatment and control groups in expressive vocabulary (verbal naming of food based on nutrition). In comparison to the control group, the treatment group's mean value was greater and the difference was statistically significant (treatment mean: 7.27, SD: 1.80; control mean: 4.51, SD: 1.73; t=7.56, df=64, p=.000). Additionally, when it came to animals' verbal naming (a component of expressive vocabulary), the mean value for the treatment group was higher than that of the control group and the difference was statistically significant (treatment mean: 7.67, SD: 1.11; control mean: 4.606, SD: 2.51; t=6.37, df=64, p=.000). As to our reflection, the AR application encourages children to learn about various animal and nutritional choices. Illustrations, sounds, and images were used in the AR application to present these elements. For the preschoolers, AR worked as an additional facilitator or teacher. The treatment group's mean score for the aggregate expressive vocabulary (the sum of naming familiar nutrition and animals) was higher, with a statistically significant difference compared to the control group (treatment mean: 14.97, SD: 1.97; control mean: 9.12, SD: 3.79; t=7.875, df=64, p=.000).

Discussion

Children’s Literacy Skills

The aggregate results for the AR supported children (treatment) were higher compared to non-AR supported children (control). This implies that AR intervention enhances holistic literacy competencies. This is consistent with other studies in a sense that AR enhanced storytelling improved children’s engagement, attention, and performance (Cheng & Tsai, 2020). However, the AR supported children did not out-perform in various areas of literacy, including expressive vocabulary, letter tracing, letter identification, phonological awareness, and special vocabulary. This might be attributed to age distribution between the treatment and control groups. The control group had more 6+ years (17 vs.14) compared to the treatment group and this has a significant impact on children’s literacy development and potentially undermines the impact of AR intervention. Other studies noted that early literacy development is age-dependent and minor age difference can impact literacy development (Piasta & Wagner, 2010), and older children typically exhibit advanced literacy skills (Hulme et al., 2015). Furthermore, gender distribution between treatment and control group was not the same. Boys in control groups (19 vs. 11) were higher than the treatment, and girls in treatment groups (22 vs.14) were higher than the control group. Previous study has shown that girls often outperform boys in early literacy tasks (Lervåg et al., 2009), demonstrating that gender might be the confounding factor for the results.

Augment Reality and Children’s Speaking Skills

Regarding to children speaking skills, AR as a learning tool did better than their peers in the area of expressive vocabulary. These children could make verbal or numerical requests for well-known foods and animals. In comparison to groups that did not get the AR support, those who were exposed to it demonstrated greater performance and a higher level of verbal expression. The children that were more verbally expressive appeared to benefit from the AR application's capabilities. Similar outcome has been identified in other research in this regard. Participants from the treatment group, who utilized an AR-based application, demonstrated higher conceptual skills when compared to those from the control group, who received standard teaching approaches. According to studies, children who are exposed to AR have a wider vocabulary (Santos et al., 2016). The utilization of compelling visual and aural components in this technology is said to successfully target teaching while improving users' conceptual understanding (Hassan et al., 2021). When compared to conventional 2D desktop interfaces, AR technology enhances learning and memory in pupils. Preschoolers' pronunciation issues have been successfully addressed by speech-based augmented reality software. The use of AR has improved engagement and made learning enjoyable for children. Given that children are prone to losing interest, AR's allure and thrill can keep them interested (Aladin, 2020). Additionally, kindergartens are important for young children's linguistic development because early childhood is a crucial time for vocabulary expansion (Miralpeix, 2006).

AR features also contribute to have higher performance in verbal naming skills as it is evident in this study. In addition to traditional tools, various resources are available to aid children in learning new words, with AR-based applications proving to be the most successful (Chen & Chan, 2019). AR applications inherently incorporate real-world location data into the produced images. This integration suggests that if knowledge is associated with real-world locations, people can easily recall and retain it (Fujimoto et al., 2012). Users of AR-based flashcards have access to a wealth of information, including words, photos, pronunciations, animations, and videos (Nakata, 2011). AR applications that capture children's attention, spark their curiosity, and inspire them to have shown to help acquire and retain words in memory (Santos et al., 2016). The ability of AR applications to provide multiple perspectives enhances users' comprehension of concepts (Roopa, 2023). By engaging more senses, AR enhances learning experiences and facilitates easier information recall (Gomes, 2014; Lampropoulos et al., 2021). Multi-sensory learning environments, facilitated by AR, enable preschoolers to better understand abstract phrases by making them more tangible (Fujimoto et al., 2012). According to constructivism theory, preschoolers can develop confidence and motivation by completing tasks in unique and engaging learning environments (Rasalingam et al., 2014). In the context of augmented reality applications, animals commonly seen by children were chosen based on the constructivist theory. These animals were presented with their young and shelters, accompanied by sounds and varied movements, creating an engaging learning environment. Augmented reality technologies now allow children to actively engage with digital content and integrate new knowledge into their existing knowledge bases (Wang et al., 2018).

Lack of significant results in expressive language and phonological awareness might be attributed to lack of AR based learning contextual engagement. It is stated that lack of improvement in expressive language implies AR may not standby for social-verbal interactions critical for language development (Hassinger-Das et al., 2020). Another study also indicates that phonological awareness is dependent and strongly influenced by AR phonics instruction and the development of phonological awareness is gradual (Lonigan et al., 2009). Furthermore, voice explanations delivered through multimedia tools contribute to the development of phonological word knowledge and its application in sentence comprehension (Lin & Wu, 2013), which AR features might not include and address them.

Augment Reality and Children's Reading Skills

Despite the fact that the mean difference for the treatment group was found to be higher in letter identification and phonological awareness, the difference between the treatment groups in reading skills is not statistically significant. It's crucial to remember that the lack of statistical significance does not imply that there are no real differences between the groups. Simply put, it indicates that the observed difference is insufficient to rule out the possibility of chance. Insignificant result might also indicate this foundational skill might be well-developed in both groups prior to the intervention that hamper the effect of AR support. On the contrary, different researches augmented the AR's contributions to reading abilities. According to Bhadra et al. (2016), augmented reality has the potential to help children improve their reading abilities. Study uncovered that AR supports to learn the alphabet and learn as well as responsible to improve children's reading skills (Ablyaev et al., 2019). According to research (Su et al., 2018), augmented reality (AR) technology can improve sensory stimulation, which in turn can boost children's attention and increase the effectiveness of learning word recognition. Every letter and every word should be accompanied with a three-dimensional visualisation and animation to make learning considerably more interactive. This helps children quickly retain new information and increases their visibility, dynamism, and sensitivity (Ablyaev et al., 2019). According to the findings, the AR alphabet book could help preschoolers learn in a fun atmosphere (Rambli et al., 2013). Preschoolers can learn abilities including environmental awareness, attention control, memory practice, vocabulary expansion, reading instruction, creativity, sound recognition, and software use through augmented reality-based applications (Kelpien, 2020).

Augment Reality and Pre-Writing Skills

In terms of average mean score when tracing words, the treatment group was better than the control group. It was determined that the difference was statistically significant. This is consistent with other study as Wang et al. (2021) suggested that digital interactive tools can enhance children's fine motor coordination, which is essential for writing skills. However, the control group's average mean in letter tracing was higher than the treatment group though it was not statistically significant. This might be related to the way the AR is being instructed and the children from both groups might have already developed this skill before the intervention. Despite the fact that the application provided a space for children to trace words and letters, letter tracing performance was not noteworthy. Teachers' practices-guiding methods may be the root of the issue, and AR features may not be providing children with enough opportunities to practice pre-writing as they ought to. In terms platforms, the AR application creates the opportunity for children to write and trace letters and numbers. In terms of the role of AR in enhancing writing skills, research indicated that AR improves children's writing skills by creating a dynamic, interactive learning environment by overlaying digital content onto real-world exercises. This encourages critical thinking and creative composition, transforming traditional writing exercises into captivating experiences (Smith et al., 2020). AR also helps children visualize and develop descriptive and expressive writing skills by allowing them to interact with 3D models, making writing more engaging and refining language choices (Brown & Chen, 2018). Further, the technology enhances peer collaboration and feedback in writing, allowing children to co-create stories and provide real-time feedback, improving editing and revising skills and collectively improving their writing (Dunleavy et al., 2019) as well as AR was found useful to teach literacy skills (Garzon et al., 2000; Sommerauer & Müller, 2018) and efficient for fostering children's arithmetic skills (Lin & Chang, 2015).

Children's Numeracy Skills

The aggregate mean result for early numeracy skills among AR-supported children was higher and statistically significant compared to that of children who did not receive support. However, the imbalance in age distributions between the treatment and control groups raises concerns regarding developmental comparisons of early numeracy skills. The control group has older children (19 vs. 11) compared to the treatment group, suggesting that age-related advantages may enable children to perform better independently of the intervention. In this regard, research has indicated that the acquisition of early numeracy skills is associated with children's cognitive maturation (Dowker, 2008). Furthermore, gender is another confounding factor in this study. The control group has more boys (19 vs. 11) than the treatment group, while the treatment group has more girls (22 vs. 14) than the control group. Prior studies indicate that boys and girls acquire early numeracy skills differently, with boys excelling in spatial and mental transformation tasks (Levine et al., 2012). Besides, Cheng and Tsai (2020) stipulate that AR enhances motivation and persistence in learning numeracy concepts.

Augmented Reality and Number Sense and Counting

The mean scores for forward and backward counting were higher and statistically significant for the treatment group compared to that of the control group, implying AR based learning fosters working memory and numerical recall. Overall, poorly designed AR content and inappropriate animation that distract children’s attention and over simplicity with technology might reduce its efficacy. This is aligned with Butterworth et al. (2011), who emphasized that interactive digital learning environments reinforce memory-related numerical skills by boosting engagement and repetitive practice. It is also indicated that AR’s capacity to improve visual spatial skills and working memory through interactive 3D modeling and real-time feedback (Bacca et al., 2014; Alloway, 2006). Preschoolers often struggle to visualize objects mentally, and integrating real and virtual environments facilitates their understanding of situations and problems. Given their developmental characteristics and pedagogical context, it is well-established that children in preschool engage more actively and learn better when games and enjoyable activities are involved (Dyson, 2018). Play serves as the foundation for reading and learning, allowing children to connect with their surroundings, think critically, explore ideas, and gain valuable experiences. Moreover, educational software, as emphasized by Dyson (2016), should incorporate elements of fun.

Nevertheless, in comparison to the treatment group, the average value for the control group was greater and statistically significant in number identification. This is not consistent with previous study, indicating that AR improves children's numeracy skills by transforming ordinary objects into dynamic puzzles or games (Bacca et al., 2014). According to Price and Rogers (2004), physical interactions facilitated by AR technology are crucial for promoting motivation, focus, and attention in engaging and educational environments. By overlaying virtual images onto real-world settings, AR applications enable visual and highly interactive forms of learning (Bower et al., 2011). Consequently, AR creates an engaging and instructive setting (Gibson et al., 2008), with a particular focus on examining the types and levels of interactions children experience with AR applications. A study indicated that the use of AR in preschool education positively influenced children's engagement, motivation, and learning. The interactive nature of AR enhanced children's spatial understanding and cognitive skills, providing them with an immersive and engaging learning experience (Vavoula et al., 2019). Congruently, in the current study, children who were supported with AR achieved better compared to those who hadn't in backward and forward counting. In the areas of forward digit span and backward counting the treatment group outperformed the control group on average.

Augmented Reality and Pattern Recognition and Matching

In matching pictures, both treatment and control groups performed higher and the difference was not statistically significant. The experiences and engagement of the two groups prior the intervention may contribute to have higher values. Previous study indicates that basic visual matching may not benefit from AR's interactive features, as traditional methods (e.g., flashcards) suffice (Garzón et al., 2019). The study further indicated that the mean score for treatment in pattern making was higher and statistically significant compared to the control group. Previous study also supported this finding that AR's dynamic visualization likely aids abstract concept mastery by enabling manipulation of virtual objects (Radu, 2014).

Augmented Reality and Number Relationship and Comparison

The study indicates that there was no statistically significant difference between AR supported children with those who didn't receive number comparison skills. The previous study suggested that poorly designed AR tools fail to enhance learning outcomes (Akçayır & Akçayır, 2017) and AR's efficacy is aligned with the alignment of learning objectives (Bacca et al., 2014). Research further indicated that shorter intervention may not achieve the required learning outcomes and suggests longitudinal intervention to have higher learning gains (Radu, 2014). It is also indicated that AR support for children to engage in learning activities is not necessarily translate to learning outcomes (Yilmaz, 2016), and non-AR environment might foster more collaborative learning (Hwang et al., 2016). Thus, AR design quality, duration, developmental appropriateness, and methodological context may affect the learning outcomes.

Augmented Reality and Special and Geometry Skills

The study revealed the differences in shape coping skills between the two groups; the group that had received AR assistance outperformed (statistically significant) the control group. AR provides hands-on learning opportunities for shape copying as witnessed in the application. This interactive experience allows them to practice fine motor skills, hand-eye coordination, and spatial precision while mimicking the shapes they see in the AR environment. This is consistent with other studies in the sense that AR expands the utilization of art and music activities. Researchers propose exploring the potential of designing applications for diverse subjects in preschool education and incorporating a wider range of objects and entities within these applications (Aydoğdu et al., 2021).

On the other hand, the mean difference between treatment and control group in mental transformation was not found to be statistically significant. This is not consistent with other findings, suggesting that with the aid of augmented reality (AR) technology, children may delve further into the issues they face, engage with immersive 3D virtual aspects, experiment with different scenarios to analyze them, and make generalizations by comparing them. Children are encouraged to use their mental and cognitive capacities through these encounters (Nicolopoulou, 2004). By enabling children to visualize and engage with educational content in a three-dimensional world, augmented reality (AR) technology empowers youngsters and gives their learning an increased sense of immersion. AR goes beyond the restrictions of the conventional classroom setting and creates new opportunities for learning experiences. Students are urged to participate in group learning activities and make connections between what they are studying and actual circumstances using AR. AR delivers an engaging and instantaneous learning environment by superimposing virtual things over the real world, encouraging more engagement and immersion among children. One of the key advantages of AR is its capability to bring abstract or invisible concepts to life, enabling students to comprehend them more easily by making them tangible and accessible. Consequently, this feature contributes significantly to enhance conceptual understanding and knowledge retention, as supported by Wu et al. (2013), and children can actively participate in the educational process while also having fun and learning by utilizing augmented reality (AR) technology (Wardle, 2000). Moreover, it is suggested to design the technology with AR's limited emphasis on spatial reasoning or insufficient task integration (Yuen, 2011).

Conclusion and Recommendation

Conclusions

Based on the results obtained from the study, certain conclusions can be made. AR has a positive effect on overall literacy and numeracy skills, although no statistically significant differences were found across the sub-themes of these skills. AR appears to be more effective for complex skills than for simple tasks, as the mean scores for the treatment group were higher and statistically significant for activities such as tracing words, forward and backward counting, expressive vocabulary (naming nutrition and animals), drawing shapes, and pattern making. In contrast, AR showed less effectiveness for simpler tasks such as letter identification, tracing letters, number comparison, and others. Besides, there is an age distribution imbalance, as children in the control group are older than those in the treatment group (19 vs. 11), giving older children an advantage in achieving higher performance compared to the treatment group.

While AR offers a variety of advantages, AR instruction is designed using a behavioral approach. AR does not consistently contribute positively to the development of literacy and numeracy skills. Although some activities are integrated into the program for children to use and manipulate independently, these activities are structured in a way that does not engage children flexibly or creatively. Furthermore, poorly designed AR content, the lack of a collaborative learning interface, and the adoption of strategies that fail to foster creativity and critical thinking in both teachers and children negatively impact learning outcomes. While AR allows educators to incorporate game elements and present virtual concepts, its design should integrate co-construction and constructionist methods that inspire both teachers and children to collaborate as a team in the learning process. Additionally, the AR framework was developed based on a subject-based curriculum orientation, following the principles of the old Ethiopian preschool curriculum.

Overall, children in Ethiopia's preprimary school program can benefit from the application of augmented reality in a variety of ways. Using AR in preprimary education seems a means to enhance the process and outcomes of the preprimary education program. Preprimary education needs to take AR into account as an additional facilitator or teacher. The accessibility of preschool education in Ethiopia can be improved, in particular, adopting AR. Therefore, AR was found that the app was a crucial teaching resource at helping preschoolers with some of the sub-tasks of literacy and numeracy.

Recommendations

The following recommendations are forwarded based on the results of the study.

- The results of the research indicate that adopting augmented reality as a learning tool is suitable for some of the tasks in literacy and numeracy skills in pre-primary education. The way our smartphones or other technological devices enhance pre-primary education is how AR studies awaken us. The application also offers recommendations for how to effectively include it into our program for pre-primary teacher preparation and preschool curricula. In particular, ICT for preprimary teachers is included into the certificate and diploma program (MoE, 2023). Teachers are expected to learn knowledge, skills, and attitude about this application. Critical AR features are also missing. As a result, it demands revision in order to include crucial information, with the advice of experts in the field of early childhood education.

- Play-based Learning (PBL) needs to infuse with AR application. Both play and learning are intertwined and cannot be separated. It is necessary to redesign AR applications with PBL in mind. PBL is discussed in terms of child-led, adult-guided, and teacher-directed play. Everything is connected to play because children love to play. Therefore, it is suggested to incorporate a constructive and socially constructive strategy into an AR application. As a result, it would be ideal for AR applications to include constructive and socially constructive approach. This will support for both teachers and children active, imaginative and reflect in their work.

- Plan International Ethiopia needs to create networks with Ethiopian Telecommunication on the way to sustainably, effectively and ethically use the AR application. The wider application of the program can be enhanced with this network. Further, the AR design (after integration and appropriate to meet PBL) has to be practiced at greater sizes by Plan International Ethiopia, GOs, and NGOs. It can be used in many schools in various regions. This will support the proper scale up across the regions of Ethiopia in the future.

- Children will become addicted to this technology if there is no system in place to prevent them from using it for extended periods of time, which will have an effect on the entire learning process and outcomes. The two days schedule for AR work which is implemented in the intervention preschool of Plan International Ethiopia are considered as model to consider, although the intervention faced some challenges with it. The modality can be changed from two days to three days a week.

- Future research will focus to examine the impact of AR with a larger sample size. Evidence will be used to support the AR practices; and

- It is also necessary to involve the AAEB, educational expertise in the city and practitioners in the application process for AR so that they do not hesitate to adapt it.

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