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ORIGINAL RESEARCH PAPER

Evaluating the usability of augmented reality for teaching Multiplication to kids

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ABSTRACT

Background and Objectives: The integration of technology in education has significantly transformed the teaching and learning processes. Among the new technologies, augmented reality stands out due to its ability to provide interactive and engaging educational experiences. This technology has been able to improve students' motivation, participation, and understanding of concepts. On the other hand, multiplication, as a fundamental mathematical operation, poses a challenge for students to learn because of its abstract nature. In math subjects, augmented reality has been used to teach geometry and rarely for other areas. Therefore, further exploring the use of this technology in other areas of teaching math, such as algebra, is worth examining. The objective of this research is to explore the usability of augmented reality applications to teach multiplication. Usability is critical to investigate, as it ensures that young users can easily engage with and benefit from educational content. The difficulty of using applications and the lack of attractiveness will negatively impact user engagement. Therefore, examining usability requirements is of great importance.

Materials and Methods: The research method included an expert review and a user survey. A class of 17 third-grade students was selected from a private school, and the researchers implemented instructional plans in collaboration with teachers. The application used was designed by an Iranian group and included multiplication lessons, tests, and educational videos. Its augmented reality capability allowed students to interactively understand multiplication concepts using the phone's camera. The System Usability Scale questionnaire was used with a 5-point Likert scale that was localized for children and translated into Persian to evaluate the usability. This questionnaire included 13 questions about ease of use, interaction, and overall satisfaction with the program. The content validity of the questionnaire was checked using the CVR index, while Cronbach's alpha coefficient was used to check its reliability. The answers were analyzed using SPSS software, and the mean, standard deviation, and correlations were checked.

Findings: This research showed that the augmented reality application for teaching multiplication to children is generally usable and attractive. The questionnaire's validity was confirmed with a CVR score of 0.99, and its reliability was evaluated with Cronbach's alpha of 0.704 at an almost acceptable level. Participants found the program easy to use and engaging, and required little help from adults. Correlation analysis showed that the need for more help was negatively related to decreased confidence in performance, while a better understanding of the program was positively related to willingness to continue working with it.

According to an expert review, the design of the program was compatible with the cognitive needs of children and uses simple design, bright colors, and attractive characters; However, the use of a small font and the lack of in-app audio and visual guides were among its weaknesses. Physically, the app had large buttons, well-spaced components, and simple menus that made it easy to work with. In terms of social-emotional needs, it was possible to choose a male or female narrator and use the augmented reality feature, but there were no customization options such as changing the background or characters, and gamification elements such as scoring or creating a sense of progress.

Conclusions: Incorporating augmented reality applications into math education can increase student engagement and motivation, but considerable attention to usability guidelines and improvements in app design are necessary. This research, in addition to highlighting the

principles that are necessary in the design of the user interface of the augmented reality program for teaching multiplication, to make it attractive and easy to use for children, has taken an innovative step in the evaluation of educational programs by presenting the Persian version of the System Usability Scale questionnaire for children, using a systematic approach to translate and localize the questionnaire.

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مقاله پژوهشی

ارزیابی کاربردپذیری واقعیت افزوده برای آموزش ضرب به کودکان

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پیشینه و اهداف: ادغام فناوری در آموزش، فرآیندهای آموزش و یادگیری را به طور قابل توجهی متحول کرده است. در میان فناوری‌های جدید، واقعیت افزوده به دلیل توانایی آن در ارائه تجربیات آموزشی تعاملی و جذاب برجسته است. این فناوری توانسته انگیزه، مشارکت و درک مفاهیم را در دانش آموزان بهبود بخشد. از سویی دانش‌آموزان برای یادگیری ضرب، به عنوان یک عملیات ریاضی اساسی، به دلیل ماهیت انتزاعی آن، با چالش مواجه هستند. در دروس ریاضی، واقعیت افزوده معمولاً برای آموزش هندسه و به ندرت برای سایر زمینه‌ها استفاده می‌شود. بنابراین، بررسی بیشتر استفاده از این فناوری در زمینه‌های دیگری آموزش ریاضی مانند جبر حائز اهمیت است. هدف این تحقیق بررسی قابلیت استفاده برنامه‌های کاربردی واقعیت افزوده برای آموزش ضرب است. قابلیت استفاده یا کاربردپذیری از اهمیت بالایی برخوردار است، زیرا اطمینان می‌دهد که کاربران به‌راحتی می‌توانند با محتوای آموزشی تعامل داشته و از آن بهره‌مند شوند. سختی استفاده از برنامه‌های کاربردی و جذاب نبودن آنها تاثیر منفی بر میزان بهره برداری کاربران خواهد داشت و بنابراین بررسی ملزومات کاربردپذیری از اهمیت بسیاری برخوردار است.

روش‌ها: روش این تحقیق شامل بررسی تخصصی و نظرسنجی از کاربران است. یک کلاس متشکل از ۱۷ دانش آموز کلاس سوم از یک مدرسه خصوصی انتخاب شدند و محققان طرح‌های آموزشی را با همکاری معلمان اجرا کردند. برنامه کاربردی مورد استفاده توسط یک گروه ایرانی طراحی شده و شامل درس ضرب، تست و فیلم آموزشی می‌باشد. قابلیت واقعیت افزوده این برنامه به دانش‌آموزان اجازه می‌دهد تا مفاهیم ضرب را با استفاده از دوربین گوشی به طور تعاملی درک کنند. برای ارزیابی کاربردپذیری این برنامه پرسشنامه مقیاس کاربردپذیری سیستم با مقیاس ۵ گزینه‌ای لیکرت که برای کودکان بومی سازی و به فارسی ترجمه شد، استفاده شده است. این پرسشنامه شامل ۱۳ سوال در مورد سهولت استفاده، تعامل و رضایت کلی از برنامه بود. روایی محتوایی پرسشنامه با استفاده از شاخص CVR و پایایی آن به کمک آلفای کرونباخ بررسی شد. پاسخ ها با استفاده از نرم افزار SPSS مورد تجزیه و تحلیل قرار گرفت و میانگین، انحراف معیار و همبستگی‌ها بررسی شد.

یافته‌ها: نتایج این تحقیق نشان داد که کاربرد واقعیت افزوده برای آموزش ضرب به کودکان به طور کلی قابل استفاده و جذاب است. روایی پرسشنامه مورد استفاده با نمره CVR برابر با ۰/۹۹تأیید شد و پایایی آن با آلفای کرونباخ ۰/۷۰۴ در سطح تقریباً قابل قبولی ارزیابی شد. شرکت‌کنندگان این برنامه را برای استفاده آسان و جذاب یافتند و نیاز به کمک

زیادی از طرف بزرگسالان برای کار با برنامه نداشتند. تجزیه و تحلیل همبستگی نشان داد که نیاز به کمک بیشتر با کاهش اعتماد به عملکرد رابطه منفی دارد، در حالی که درک بهتر برنامه به طور مثبت با تمایل به ادامه کار با آن مرتبط است.

نتیجه بررسی خبرگان نشان داد که طراحی این برنامه با نیازهای شناختی کودکان سازگار بوده و از طراحی ساده، رنگ‌های روشن و شخصیت‌های جذاب استفاده شده است. اما استفاده از فونت کوچک و نبود راهنمای صوتی و تصویری درون برنامه از نقاط ضعف آن بود. از نظر فیزیکی، برنامه دارای دکمه‌های بزرگ، اجزای با فاصله مناسب و منوهای ساده بود که کار با آن را آسان می‌کرد. از نظر نیازهای عاطفی اجتماعی، امکان انتخاب راوی مرد یا زن و استفاده از ویژگی واقعیت افزوده وجود داشت، اما هیچ گزینه سفارشی‌سازی مانند تغییر پس‌زمینه یا شخصیت‌ها و عناصر گیمیفیکیشن مانند امتیاز دادن یا ایجاد حس پیشرفت وجود نداشت.

نتیجه‌گیری: گنجلندن برنامه‌های واقعیت افزوده در آموزش ریاضی می‌تولند تعامل و انگیزه دانش‌آموزان را افزایش دهد، اما توجه به دستورالعمل‌های کاربردپذیری و بهبود در طراحی برنامه‌های کاربردی ضروری است. این پژوهش علاوه بر برجسته کردن اصولی که در طراحی رابط کاربری برنامه واقعیت افزوده برای آموزش ضرب لازم است رعایت شود تا استفاده از آن را برای کودکان جذاب و آسان نماید، با ارائه نسخه فارسی پرسشنامه مقیاس کاربردپذیری سیستم برای کودکان و با رویکردی نظام‌مند برای ترجمه و بومی‌سازی پرسشنامه گامی نوآورانه در ارزیابی برنامه‌های کاربردی آموزشی برداشته است.

Introduction

Instructional design plays an important role in the development of learning tools, and the integration of modern technologies such as augmented reality requires the use of instructional design principles to enhance effectiveness and engage learners. Learning theories such as constructivism, active learning, and game-based learning can contribute to improving the process of teaching mathematics.

Mobile Augmented Reality (AR) apps are becoming revolutionary tools in education, offering fun and engaging ways to help students learn. With smartphones and AR technology becoming more accessible, researchers explore how these tools can create interactive and immersive learning experiences. One area where AR can make a difference is teaching young kids fundamental math concepts, like multiplication. By blending digital visuals with the real world, AR helps bring abstract ideas to life, turning traditional lessons into exciting, hands-on learning adventures. AR can be used to enhance Mathematics perception, which is essential for developing effective educational strategies [1].

Teaching multiplication can sometimes feel like an uphill battle. Kids need to grasp number relationships and memorize times tables, which isn't always easy. Traditional methods might not hold their interest for long, leading to frustration or disengagement. That's where mobile AR apps come in, offering a fresh approach. By using interactive visuals, real-time feedback, and even gamifying the learning process, these apps make learning multiplication more exciting and accessible. Kids can visualize and interact with numbers in a way that makes the material easier to understand and remember.

While the potential benefits of AR in education are substantial, some challenges exist that need to be addressed for successful implementation. These challenges include the need for teacher training, the integration of AR into existing curricula, and technological barriers. [2, 3]. Further, it is important to design and develop user-friendly applications. Usability in educational applications plays a fundamental role in engaging students and enhancing user interaction. A simple, fluent, attractive user interface helps students access academic content and understand concepts better without feeling confused or tired. If the application is complex and difficult to understand, users will quickly lose interest, and learning will be hindered. Therefore, user-friendly design implementing the principles of user experience (UX) and usability can increase user involvement and make learning an enjoyable and effective experience.

To make AR apps truly effective for kids, they need to be designed with kids in mind. Evaluating how usable these apps are is a key part of ensuring they hit the mark. Usability testing looks at how simple and enjoyable an app is for children, considering things like how easy it is to navigate, how well the design fits their needs, and how responsive it is. Since kids' abilities and preferences differ from adults, it's crucial to think about their unique needs. An app's success depends on how intuitive it is, whether the content is appropriate for their age, and how well it keeps them engaged.

Beyond usability, it's also essential to see if the AR app truly helps with learning. The best educational AR apps are not just easy to use, but they also encourage active participation, problem-solving, and practice. By evaluating both how user-friendly and effective the app is at teaching multiplication, developers and educators can ensure these tools are not only fun but also help kids succeed in their learning journey. However, the focus of this study is just on the usability of the AR app for teaching multiplication to children. This research aims to evaluate the users' and experts' feedback regarding augmented reality software for teaching multiplication, to examine aspects of how such software should be designed.

The contribution of this research, besides exploring the usability of AR applications to teach multiplication, is providing a Persian version of the System Usability Scale questionnaire for kids. The SUS is designed for adults in its standard mode, but for children, it needs to be simplified and localized to suit their cognitive and language abilities. Preparing the SUS questionnaire for children is especially important because this tool is used to evaluate the usability of products, systems, and software designed specifically for kids. This research uses the SUS questionnaire adapted for kids. [4] and follows a systematic approach [5] To translate the kids' SUS questionnaire into Persian, which has not been done before.

Review of the Related Literature

Each emerging technology comes with opportunities and challenges for use, particularly in education and learning. One such technology is augmented reality, which, with its capability to run on mobile phones, has shifted from purely a research topic to a practical application. Augmented reality software enables students to visually understand concepts and interact with virtual elements from various angles, sometimes even allowing them to design objects.

The advantages of using augmented reality for students include increased motivation, attention, interaction, satisfaction, and focus. As a result, the student's interest in the subject grows, leading to a better learning experience and faster progress. One of the benefits of augmented reality is the ability to receive additional information simultaneously, which allows students to view content practically and from different perspectives, thereby increasing their motivation to learn and strive further [6].

Since learning is not always possible through a single approach, methods such as games and simulations that serve specific educational purposes can be not only enjoyable but also enhance learners' engagement, depth, and retention [7]. Using innovative and creative methods can positively impact students' interest in learning and promote cohesion and retention in learning [8]. Augmented reality applications, with their unique features, can provide significant assistance in this regard [6].

Another important aspect of using AR technology is educating individuals with learning disabilities or special needs. Augmented reality capabilities, such as adding sound to concepts for those with visual impairments or adding text to describe images for those with hearing difficulties, can help reduce these individuals' learning limitations. It can even aid those with physical limitations in their hands and feet [9].

Currently, AR technology has become very popular in education, especially in mathematics, and its use has facilitated the teaching and learning of mathematics [10]. In teaching and learning mathematics, augmented reality technology offers significant advantages. A study conducted by Rohendi and Wihardi [11] among secondary school students in Indonesia showed that the use of AR increased spatial learning activities in geometry. Using AR can also help students better understand concepts related to 3D shapes. In another study conducted in Türkiye, researchers found that the mobile-supported learning environment in the field of algebra has a positive effect on the academic achievement and motivation of secondary school students [12].

The effect of using AR in math education is classified into two cognitive and affective domains. In terms of cognitive influence, it enhances conceptual knowledge [12-15], procedural knowledge [12, 13, 15], and academic achievement [12, 14]. These results show that AR technology had the greatest impact on students' conceptual understanding. In terms of Affective impact, students' attitudes [15, 16] and motivation [12, 14] are influenced.

Ivan and Matt conducted research where AR technology has been used in three main math subjects in secondary education, including geometry, algebra, and statistics & probability [17]. Their findings show that AR has been used more in geometry due to its 3D visualization capability. Since one of the core components of the school mathematics curriculum is algebra, it is vital to investigate further how new technologies such as AR can enhance algebra teaching and learning. Some view algebraic thinking in mathematics as a gateway to higher education and greater opportunities for successful participation in society and the technology market.

As basics for algebra, in elementary mathematics, the most important relationships to be emphasized involve the connections between arithmetic concepts, such as the relationships between numbers, the connections between numbers and the four basic operations, and the interrelations of these operations [18]. Some of the relationships presented in third-grade math textbooks include multiples of a number, patterns in the multiplication table, the relationship between multiplication and addition, and the relationship between multiplication and division. So, multiplication is one of the important topics of third-grade mathematics.

Teaching and memorizing the multiplication table is crucial for understanding and applying these relationships. Teaching multiplication poses a challenge for third-grade students, teachers, and even parents, as it requires integrating with students' memory and is more complex than addition and subtraction [19]. In traditional mathematics instruction, emphasis is mostly placed on repetition and practice. This approach does not account for students' differences, talents, or interests. Therefore, suitable methods must be devised, and multisensory techniques should be employed to ease the learning process. AR technology can help in this regard [6].

Rebollo and her colleagues [6] researched the design and evaluation of an AR game to learn multiplication. The purpose of the research was to implement a more attractive method to practice multiplication using two mini-games, one with the genre of turn-based combat and the other with the genre of throwing objects. To make it more interesting, the games used augmented reality technology, which enables the display of game images and scenes in the users' real environment, thus improving the learning experience. In this study, a test was conducted with the participation of 8-9-year-old children. They were divided into two experimental and control groups; The experimental group used the augmented reality game to practice the multiplication table, and the control group traditionally used the exercise book. Children in the experimental group interacted more with the activity and showed more enthusiasm than the traditional method. In this study, a researcher-made questionnaire containing 13 questions with a 5-point Likert scale, which investigated the satisfaction and ease of using the program, was used. Evaluations indicated the game's user-friendliness and ease of use on smartphones, although some children felt bored at times. The authors suggested improvements in augmented reality interaction and social game development as future work.

In another study Volioti et al. [20], an augmented reality program designed to enhance math learning for sixth graders through real-world problems like recipes. The program was evaluated using the System Usability Scale (SUS) and interviews with three groups: philosophy and education students, engineering students, and elementary students. Philosophy and education students rated usability highest (SUS 76.31), emphasizing its educational value and engagement benefits. Engineering students gave a lower score (65.24), citing interface issues and suggesting improvements like a help button and clearer instructions. Elementary students rated it 68.43, finding it engaging but somewhat difficult to navigate. The overall SUS score of 70.01 indicated acceptable usability, though refinements could improve intuitiveness, especially for younger users.

Hadadi evaluated the applicability of the GeoGebra educational software, which is used as a dynamic geometry tool for teaching mathematics in Australian schools. The research aimed to identify the challenges and usability issues of this software for students and teachers so that by improving the user interface, learning mathematics through the software can be optimized [21]. In this regard, the System Usability Scale (SUS) questionnaire was used to evaluate the opinions of students and teachers regarding the ease of use and attractiveness of the GeoGebra user interface, as well as the problems that novice users may encounter. In addition to the questionnaire, researchers have analyzed the qualitative responses of users. The results show that despite the positive effect of GeoGebra in improving educational achievements, some users have felt uncomfortable with the complexities of the software's user interface. The researcher recommended reducing the complexity and memory load of users, coordinating the system with the real world, minimalist and aesthetic design, prevention of errors, and support and documentation to increase the effectiveness and applicability of educational software so that learning takes place more effectively and attractively.

To make AR applications more effective, applying usability guidelines and designing apps that are user-friendly is essential. The design aspects of using technology and specifically AR applications in education to help further learning impacts are vital. Generally, researches focus on the learning effects of using AR in education, and the usability aspects of these apps are rarely investigated.

Further, to develop applications for kids it is vital to address their specific needs since children's preferences are significantly different from adults. As for adults, usability evaluation of apps for kids is important. Usability focuses on easy and enjoyable use of the system and is dependent on easy navigation, responsiveness, and suitable design which significantly affects kids using educational apps. Therefore, due to the importance of making learning math, and particularly multiplication, easier and more enjoyable for kids, this research introduces an Iranian AR application in this field and explores its usability to highlight the design requirements of such applications. AR applications are mostly investigated in geometry teaching [17] and rarely are used in teaching algebra and specifically multiplication. Therefore, the current research is novel in this aspect too.

By focusing on usability aspects, this research provides valuable insights into the design requirements of AR applications tailored for young learners. The findings will contribute to the development of more intuitive and engaging AR-based learning tools, ensuring that they are not only educational but also enjoyable and accessible to children.

Method

The present study aims to examine the usability of educational software, with an emphasis on augmented reality, to teach multiplication to third-grade elementary school students. In terms of its objective, it is applied research, as it seeks to develop practical knowledge in a specific field.

Participants

A third-grade class consisting of 17 students, from a private school was selected.

Instruments

The method is a combination of expert review and user survey. Researchers from the usability and human-computer interaction field worked with the application and analyzed its usability, considering usability guidelines [22, 23]. Further, to study the feedback of users, participants were selected by a purposive sampling method.

To evaluate the usability of products, services, and systems, various methods exist. One of the most common tools for assessing usability is the SUS questionnaire, introduced by Brooke in 1996 [24]. This questionnaire was initially developed as a tool to measure the subjective usability of industrial systems.

The SUS questionnaire has been used for many years across different fields and structures, demonstrating high efficiency. Additionally, due to its speed and ease of usability measurement, it has attracted significant attention from researchers [25]. Bangor and colleagues, after ten years of studying this questionnaire, concluded that SUS is a highly robust tool with diverse applications [26]. In a comparison between the SUS questionnaire by Brooke and a newer questionnaire introduced in 2009 by Lewis and Sauro, it was shown that the SUS questionnaire is much more suitable for accurately evaluating usability [27].

Therefore, in the last session, the SUS (System Usability Scale) questionnaire with a 5 Likert scale was distributed to the students, the researcher explained its questions to them, and asked them to provide their responses. The SUS questionnaire used in this research is the one adapted for kids [4]. This questionnaire consisted of 13 questions designed to evaluate different aspects of the program, such as ease of use, interaction, and overall satisfaction. Based on Putnam and her colleagues' recommendation, the symbols shown in Fig. 1 were used for answers.

Fig. 1: Symbols for the questionnaire answers [4]

Since this study was conducted in Persian, the questionnaire was translated into Farsi. As the first step to perform the linguistic validation, the main questionnaire was translated into Farsi, using the standard method of backward-forward [5]. Therefore, questions were first translated into Farsi independently by two language experts. Then, two other independent translators did a reverse translation. Finally, to ensure that both English versions are equivalent to each other and have the same meaning, they were compared with the original version, and after choosing a semantic equivalent and a suitable term for words to adapt the questionnaire with multiplication application, the final version of the translation was prepared.

Evaluation of Face Validity of the Questionnaire

Face validity is an objective judgment regarding the structure of the instrument and addresses the following questions:

- Do the individuals who are supposed to respond to the questions agree with the wording and phrasing of the instrument?
- Does the interpretation of non-expert respondents (the target group) align with the researcher's intended meaning?
- Are the overall structure and components of the instrument acceptable to the respondents? [28]

To determine the face validity of the questionnaire, it was reviewed by 5 university professors specializing in education, educational technology, and information technology. They were asked to evaluate the difficulty level, inconsistency, ambiguity of statements, and potential deficiencies in word meanings. Based on their feedback, minor modifications were made to the questionnaire to enhance its clarity and appropriateness.

Content Validity Assessment of the Questionnaire and AR Content

Content validity addresses the following questions:

- Does the designed instrument cover all essential aspects of the intended concept?
- Do the constructs of the instrument measure what they are supposed to assess?
- Are the overall structure and components acceptable to relevant experts? [28]

The content validity of the questionnaire was evaluated using the Content Validity Ratio (CVR) and the Content Validity Index (CVI). The Average Content Validity Index (S-CVI/Ave) was also calculated.

In this study, the CVR was evaluated, using education (1), which is presented by Lavshi [29]. Both the questionnaire and the AR content of the program were given to 5 experts and asked them to express their opinion precisely about each question of the questionnaire in three judgment scales: "necessary", "useful but unnecessary", and "unnecessary". Further, they were asked to assess the alignment of the AR content with the educational objectives of the multiplication table. In Lawshi's suggested method, the minimum number of respondents is 4. In the CVR equation, n is the total number of people who answered, and n_e is the number of people who found the questions necessary.

$$CVR = (n_e - \frac{n}{2})/(\frac{n}{2}) \quad (1)$$

The CVI was calculated based on the Waltz and Basel method [30]. According to Ayre and Scally, a CVI score of 0.79 or higher is recommended for item acceptance. If the CVI score is between 0.70 and 0.79, the item requires revision and refinement. Items with a CVI score below 0.70 should be eliminated [31]. In this method, experts are asked to evaluate the level of relevance, simplicity, and clarity of each question on a 4 Likert scale. The CVI was calculated using the Waltz and Bausell formula. For each question, the average of simplicity CVI, relevance CVI, and clarity CVI is calculated.

The average content validity index (S-CVI/Ave) for the questionnaire was calculated based on the mean CVI scores of all items. According to Polit and Beck, a score of 0.90 or higher is recommended for acceptance [32]. The CVI score for each item was determined by dividing the number of experts who rated the item as 3 or 4 (highest scores) by the total number of experts. This method ensures that only the most relevant, clear, and simple items are retained in the final questionnaire.

The reliability of the questionnaire was assessed by calculating Cronbach's alpha, which was 0.704. To assess the reliability of the AR content, the test-retest reliability method [33] was used. Students interacted with the program again after two weeks, and the results were compared. The obtained Cronbach's Alpha value was 0.78, indicating an acceptable level of educational content reliability.

To analyze the results of the questionnaire using SPSS software, Mean, Standard deviation, and Pearson correlation were calculated. A Pearson correlation analysis was also conducted to examine the relationship between the level of assistance needed in using the app, trust in its performance, and the willingness to continue using the app.

Procedure

Before conducting the study with students, one of the researchers, coordinated with the relevant authorities to implement the research at the school. Then teaching methods were explained to the teacher, the educational application was introduced, and a copy was provided to the teacher for familiarization, working with the environment, and installation. Given the number of students, four programs were prepared by the researcher and installed on four mobile phones.

The augmented reality multiplication application that was used in this study is based on a marker and was developed by an Iranian programming group called Persia. The related app can be downloaded and installed through the corresponding website (https://parsia-app.ir/2023/06/26/zarb/). This program includes a page where entering a code activates the program. The program environment features multiplication tutorials, categorization, tests with two difficulty levels (easy and difficult), educational videos for the concept of multiplication, multiplication rules, multiplying a two-digit number by a one-digit number, multiplying a two-digit number by a two-digit number, multiplying fractional numbers, and multiplying decimal numbers. The AR content included 3D animations, dynamic numerical displays, touch interaction, and visual simulations of mathematical problems, all of which were tailored according to interaction design principles for digital learning environments.

Since the application used in this research is not developed by researchers, this study did not aim to examine the technical standards of software design and development, but focused on evaluating the software's performance in the educational environment, assessing student interaction levels, and analyzing its usability from the perspectives of users and educational experts.

However, the preliminary review revealed that the software follows some common technical standards in augmented reality development, including:

- Use of ARCore/ARKit: Support for standard augmented reality technologies for processing and displaying 3D content.
- Adequate graphical clarity: The 3D models are optimized and comply with Low-Poly Rendering design standards for mobile execution.

However, a detailed examination of the software's code and the implementation of technical standards is beyond the scope of this study.

Design

To use the augmented reality (AR) feature of this program, it can be activated at the top right corner of the screen. The mobile phone camera is turned on, and by scanning the screen, the program environment appears on the device (Fig. 2).

Fig. 2: Photos of the application

The design of educational activities in this study was based on Gagné's Nine Events of Instruction [34], which include stages such as gaining attention, presenting stimuli, providing learning guidance, practice, feedback, and performance assessment. In the augmented reality multiplication sessions, students' interaction with the content increased, and learning was facilitated through visual and interactive activities.

The lesson plans for 6 sessions, each 45 minutes, were written by the researcher with the guidance of the teacher. The general objective of session one was to familiarize students with multiplication. Students listened to the instructor's explanation and a video, then shared their understanding in groups. Using an AR multiplication app, they explored multiplication concepts by activating the AR feature and watching educational videos. After summarizing their learning, they practiced the first and second rows of the multiplication table by entering numbers into the app (e.g., 1×1 to 1×9, then 2×1 to 2×9) and observing visual examples (Fig. 3). Finally, they completed exercises in the textbook.

Fig. 3: A part of the implementation steps in the first session

The same process was conducted in the second session. After discussing and talking about drawing the axis and shapes for multiplication, students started working with numbers (teaching multiplication of 3 and 4). For this session, students should set the number in the square to 3 and the number in the circle to 1 through 9, one at a time, observing the changes. Then, they repeated this process for the number 4 (Fig. 4.)

Fig. 4: A part of the implementation steps in the second session

The other 3 sessions were assigned to learning multiplying to 5 and 6, 7 and 8, 9 respectively. In the final session, multiplication exercises at a difficult level were addressed. Six questions on the fundamentals of multiplication and the multiplication table from the third-grade elementary school textbook were designed and asked students to solve them using the application.

Results and Findings

To assess the validity of the SUS questionnaire used in this research, the CVR score was calculated, which was 1. Considering the number of respondents and referring to Lavshi's table for 5 members [29], the minimum score of 0.99 is accepted, which is the one gained in this research (Table 1). Further, all 5 experts believed that the AR content aligned with the educational objectives of the multiplication table. The experts confirmed that the educational content designed in the augmented reality environment demonstrated appropriate validity in terms of conceptual accuracy, alignment with educational principles, and compatibility with the mathematics curriculum.

According to Waltz and Bausell's method, the minimum acceptable CVI value for each question must be 0.79. The results showed that the Content Validity Index (CVI) for all questionnaire items (Table 2) met the acceptable threshold of 0.79. Finally, the Average Content Validity Index (S-CVI/Ave) was calculated, resulting in a value of 0.928, which falls within the acceptable range.

The Cronbach's alpha of the questionnaire was 0.704, which shows nearly acceptable reliability.

Even though all respondents had never used AR for learning math, they reported that The application was easy to use and understand (4.56 mean score for Q3: I think the application was easy to use). The SUS questionnaire used in this research includes positive questions, which are odd-numbered ones, plus Q12, and negative ones for even-numbered. Table 3 shows the SUS questionnaire analysis, including mean values.

Results show that the participants were very interested in using the multiplication app (Q1 (4.65)) and thought the program was easy to use (Q3 (4.65)). They found the application enjoyable (Q11 (4.41)) and tended to spend more time working with it (Q12 (4.35)). Questions with low averages indicate that working with the program was not so difficult and there was little need to do strange things to use it or ask adults for help (Q2 (1.41), Q8 (1.76), and Q4 (2.12)).

A low standard deviation in Q1, Q2, and Q3 indicates that most respondents agree on the ease of using the application. However, the high standard deviation in Q4 and Q10 shows that students had various perceptions of the learnability of the program.

To investigate if there is any correlation between questions, Pearson correlation was calculated, and where it was significant is demonstrated in Table 4.

Table 1: CVR Results and Acceptance/Rejection of Questions of the SUS questionnaire for kids

	Question	CVR	Accept/Reject
1	I think if I had the multiplication app on my phone, I would love to work with it a lot.	1	Accept
2	I often got confused when working with the multiplication program.	1	Accept
3	I think it was easy to use the multiplication program.	1	Accept
4	I think I need help from older people to work with the multiplication program.	1	Accept
5	When I was working with the multiplication program, I knew what to do next.	1	Accept
6	Some of the things I had to do while working with the multiplication program were incomprehensible	1	Accept
7	I think most of my friends can learn to work with the multiplication program very quickly.	1	Accept
8	Some of the things I had to do to work with the multiplication program were strange	1	Accept
9	I felt confident when I worked with the multiplication program	1	Accept
10	I had to learn a lot before I worked with the multiplication program	1	Accept
11	I really enjoyed working with the multiplication program	1	Accept
12	If I had more time, I would continue working with the multiplication program	1	Accept
13	I plan to talk to my friends about the multiplication program.	1	Accept

Table 2: CVI of the SUS questionnaire for kids

	Question	CVI	Accept/Reject
1	I think if I had the multiplication app on my phone, I would love to work with it a lot.	0.87	Accept
2	I often got confused when working with the multiplication program.	1	Accept
3	I think it was easy to use the multiplication program.	0.93	Accept
4	I think I need help from older people to work with the multiplication program.	1	Accept
5	When I was working with the multiplication program, I knew what to do next.	0.87	Accept
6	Some of the things I had to do while working with the multiplication program were incomprehensible	0.93	Accept
7	I think most of my friends can learn to work with the multiplication program very quickly.	0.93	Accept
8	Some of the things I had to do to work with the multiplication program were strange	0.8	Accept
9	I felt confident when I worked with the multiplication program	1	Accept
10	I had to learn a lot before I worked with the multiplication program	0.87	Accept
11	I really enjoyed working with the multiplication program	1	Accept
12	If I had more time, I would continue working with the multiplication program	1	Accept
13	I plan to talk to my friends about the multiplication program.	0.87	Accept

Table 3: Response to the SUS questionnaire

Question	Question	Mean score	Sd
Q1	I think if I had the multiplication app on my phone, I would love to work with it a lot.	4.65	0.61
Q2	I often got confused when working with the multiplication program.	1.41	0.71
Q3	I think it was easy to use the multiplication program.	4.65	0.86
Q4	I think I need help from older people to work with the multiplication program.	2.12	1.58
Q5	When I was working with the multiplication program, I knew what to do next.	4.24	1.39
Q6	Some of the things I had to do while working with the multiplication program were incomprehensible	1.94	1.43
Q7	I think most of my friends can learn to work with the multiplication program very quickly.	4.06	1.03
Q8	Some of the things I had to do to work with the multiplication program were strange	1.76	1.35
Q9	I felt confident when I worked with the multiplication program	4	1.66
Q10	I had to learn a lot before I worked with the multiplication program	3.06	1.75
Q11	I really enjoyed working with the multiplication program	4.41	1.12
Q12	If I had more time, I would continue working with the multiplication program	4.25	1.00
Q13	I plan to talk to my friends about the multiplication program.	3.29	1.72

Table 4. Pearson correlation results

Questions	Pearson Correlation Coefficient (r)	p-value	Correlation Type
Q4 and Q5	-0.668	0.003	Negative Significant
Q6 and Q8	0.574	0.016	Positive Significant
Q10 and Q12	0.705	0.002	Positive Significant
Q4 and Q13	-0.566	0.018	Negative Significant

Results demonstrate a negative correlation between Q4 and Q5 (-0.668 with sig=.003), meaning that Individuals who feel that they need assistance in using the app may feel less comfortable using it, and as a result, may require more guidance and direction to predict their next steps. This negative correlation could indicate that trust in the app's performance and the ability to use it independently have an inverse relationship.

Q6 and Q8 (0.574 with sig=0.016) are positively correlated, indicating that issues in understanding the app's functions could be associated with a sense of incompatibility or the unusual nature of some of its tasks and features. In general, a negative experience with the user interface or the app's complexities could lead to feelings of confusion or strangeness regarding the tasks.

A positive correlation is also observed between Q10 and Q12 (0.705 with sig=00.2), which can be interpreted as even if students feel that they need to learn more, they are still interested in continuing to use the app and are willing to spend more time mastering it.

Further, Q4 and Q13 (−0.566 with sig=0.018) are negatively correlated, suggesting that as the need for assistance in using the app increases, there is less willingness to talk to friends about the app. In other words, individuals who require more help may be less inclined to discuss and share their experiences with others.

The result of the expert review is as follows: in terms of cognitive requirements, the application uses simple designs, bright colors, and attractive characters for children. Fonts are mostly readable; however, instructions are in a small font, which is not suitable for children. Complex and heavy texts are not used. Audio and visual guidance are not provided for children except for multiple small font sentences. Finally, it provides immediate and positive feedback to confirm children's correct or incorrect answers. Further, it lets children do the test without penalty.

In terms of physical requirements, buttons are large enough that children can click them without making a mistake, and they are placed at a suitable distance from each other to avoid the wrong touch. Only simple gestures, such as tapping, are required. No complicated menu is designed in this application. The child can easily return to the main page or choose the next activity.

In terms of Socio-Emotional requirements, children can select a man or woman narrator and choose to use AR or not; however, no other personalization option, such as changing background or characters, is provided. Two levels of hardship are selectable. This app contains no advertisements or external links that can confuse children. Gamification elements such as scoring, stars, coins, or unlocking new levels are not used. The game doesn't give the child a sense of progress and success. Children can't have personal profiles in this application.

From an instructional design perspective, the augmented reality-based multiplication program had strengths such as the use of engaging visual images, interactive exercises, and the provision of instant feedback. However, experts suggested that to enhance educational effectiveness, approaches like multisensory learning, adaptive learning tailored to students' levels, and gamification could be utilized.

Discussion

The results of this study indicate that the AR-based multiplication app was generally well-received by third-grade students, showing positive usability and engagement outcomes. High mean scores for statements like "I think using the app was easy" (Q3, 4.65) and "I enjoyed working with the app" (Q11, 4.41) demonstrate that the application succeeded in delivering an enjoyable and intuitive learning experience. These findings are in line with previous studies, such as Rebollo [6] and his colleagues showed that augmented reality programs can make the learning experience more interactive and engaging and increase student engagement. Additionally, students stated a strong inclination to continue using the app, as reflected in Q12 (4.25). This suggests that integrating interactive AR tools into the classroom can enhance motivation and engagement in learning fundamental math concepts like multiplication.

On the other hand, the responses to Q2 (1.41) and Q8 (1.76) indicate that students rarely found the app confusing or required performing strange actions to operate it. Likewise, a low mean score for Q4 (2.12) expresses that most students did not feel adult assistance was necessary, reflecting the app’s ease of navigation. However, the higher standard deviation for Q4 and Q10 suggests variability in individual learning needs, where some students found the app more challenging, requiring additional guidance or prior knowledge. This is in line with the expert review that downgrades the level of learnability of the application since it does not provide in-app audio and visual guidance for children. The need for help facilities in applications is emphasized in other studies, too [20, 21].

Overall, the findings suggest that the AR-based app effectively combines usability, enjoyment, and educational value. This is in line with Zhou and colleagues [3] research, concluding that AR can attract students’ attention and encourage them to be involved with problems more deeply [35]. However, enhancements in instructional design and user guidance can further optimize the learning experience. Moreover, the app suffers from personalization options, which are emphasized in the literature [23]. By addressing individual differences [23] and ensuring clear step-by-step instructions [20, 21] , AR tools like this can serve as powerful resources for teaching multiplication, fostering both engagement and learning outcomes in young students.

This research has applications in the field of teaching and learning. The use of augmented reality (AR) can increase the motivation [12, 14] and participation [6, 17] of students in learning mathematics by providing visual and interactive content and making complex concepts, such as multiplication, more attractive and understandable. The technology can also replace traditional memorization-based methods with interactive learning methods that help students practically understand abstract concepts. The findings of this research are useful for developers of educational software and can help to design applications suitable for children, with features such as large buttons, simple menus, and personalization options.

Moreover, AR technology can also be used in the education of students with special needs, as it reduces learning limitations by adding audio and visual capabilities. App usability evaluation using tools such as the SUS questionnaire helps teachers and developers identify and improve the strengths and weaknesses of educational programs. Also, by emphasizing features such as gamification, personalization, and audio and visual guidance, this research provides solutions to improve children's learning experience and create a sense of achievement in them.

Overall, multisensory learning models and constructivism are recommended in the design of technology-based educational programs. However, to optimize this process, aspects such as providing a personalized learning path, adding visual and auditory guidance, and increasing social interaction within the learning environment need to be implemented in the educational tool.

Conclusions

This research showed that using augmented reality applications to teach multiplication to children not only provides an engaging and interactive learning experience but can also have a positive impact on understanding abstract concepts and increasing students' motivation. The usability evaluation of this program using a localized version of the SUS questionnaire for children showed that most students found this software understandable, enjoyable, and easy to use, and were willing to continue using it. However, some weaknesses were also identified, such as the lack of audio and visual guidance, lack of customization capabilities, and lack of gamification elements (such as scoring or a sense of progress) that could be addressed in future versions.

From an educational design perspective, this program made learning more engaging for children by using interactive design principles, 3D images, and immediate feedback. Also, providing a Persian version of the system usability questionnaire for children is an innovative step in evaluating digital educational programs.

Overall, the results of this study show that the design of augmented reality educational programs should be based on the cognitive, physical, and social-emotional needs of children and on the principles of usability and user-centered design so that they can be effectively used in the teaching-learning process.

The limitation of this research is the low number of participants. Moreover, this study was conducted in a private school in which most students are from high-income families and are familiar with using mobile applications. This may impact how they evaluate the application. Another limitation of this research is that only the usability of one AR application is investigated.

An important priority for future research is to increase the sample size and diversity of the statistical population, especially to include students from diverse backgrounds such as public schools, low-income areas, or students with special needs. Increasing the number of students and experimenting with the use of the AR application in other schools with different characteristics, such as schools in low-income areas, may clarify more aspects of designing effective AR applications for teaching math, specifically multiplication.

Enhancing the pitfalls of this app and developing personalization features, adding gamification elements such as scoring, badges, and advanced stages can make the user experience more engaging for students and enhance their sense of progress. Therefore, it is recommended to add these features to the app and investigate their impact on students' engagement and motivation.

Expanding the application of this technology to other algebra subjects and designing similar applications for them is another important research area.

Authors' Contribution

N. Zanjani developed the idea, prepared the SUS questionnaire, analyzed data, and wrote the manuscript. F. Fathi bought and installed the app, worked on lesson plans with the children, and helped them answer the questionnaire. M. Ajdadi, as the consultant, designed the class implementation. M.J. Eslampoor supervised the project.

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Conflicts of Interest

The authors have no conflicts of interest.

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