Development and Implementation of an Educational Mobile Application for Children with Hearing Impairments

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***Abstract*—This study investigates the development and evaluation of an educational mobile application designed for children with hearing impairments. The application incorporates game-based elements to facilitate learning and enhance engagement. The primary aim was to assess its effectiveness in improving algorithmic thinking and academic performance. The research was conducted in two stages: (1) development of the application using an inclusive design approach, and (2) experimental implementation in the educational process. The participants were 15 sixth-grade students from a specialized school for children with hearing impairments, divided into an experimental group (n = 7) and a control group (n = 8). The experimental group used the application as a supplementary tool for learning programming, while the control group followed traditional teaching methods. Pre-test and post-test assessments were administered to measure changes in performance. The results demonstrated that the mobile application significantly enhanced algorithmic thinking and improved academic outcomes compared with the traditional approach. These findings highlight the potential of accessible digital tools to support inclusive education and promote effective learning among students with special educational needs.**

***Keywords*—children with hearing impairments, educational mobile application, game-based learning, algorithmic thinking, educational tool**

I. Introduction

Based on estimates from the World Health Organization (WHO), over 5% of the global population (approximately 430 million individuals, including 34 million children) experience some degree of hearing loss. By 2050, this figure is projected to rise to nearly 30% of the population, affecting individuals at varying levels of severity. The increasing prevalence of hearing impairments necessitates further research and the development of solutions to support individuals with hearing impairments around the world [1].

The Bureau of National Statistics reports that the Republic of Kazakhstan has 18 specialized schools for children with hearing impairments, serving over 2,000 deaf and hard-of-hearing students [2]. Children with hearing impairments and deafness primarily encounter challenges in daily communication, emergency contact, and safety assurance [3]. Hashim *et al*. [4] suggest that mobile applications offer new educational opportunities for children with hearing impairments, improve their communication abilities, and promote inclusion in the educational setting.

Mobile devices, including smartphones and tablets, facilitate the creation of a personalized educational environment. This is especially crucial for children with hearing impairments who encounter difficulties in assimilating information via traditional teaching methods. Mobile applications provide visual explanations and textual content, facilitating better comprehension of the material and enhancing communication skills in children with hearing impairments [5].

Despite this potential, existing educational practices and technological interventions inadequately address the specific needs of deaf and hard-of-hearing students.

The main gaps include the limited availability of high-quality adapted mobile applications in different languages, insufficient personalization of learning experiences, and cultural differences in technology use [6]. Nevertheless, despite the potential of mobile applications in inclusive education, several challenges remain, including the need for more personalized learning approaches, limited availability of adapted applications in different languages, and cultural differences in technology use [7]. These issues require a careful approach for the development and implementation of mobile applications aimed at hearing-impaired children within the educational framework.

Students in special education schools for hearing-impaired children often encounter difficulties in skill acquisition at the expected level and in effective communication or collaboration with peers from mainstream schools [8]. This problem is caused by various circumstances. Firstly, there are few Sign Language interpreters employed in special schools, and a deficiency of specialists in higher education institutions that provide their training. Secondly, numerous families, owing to financial constraints and time commitments, are unable to employ a specialized instructor to teach sign language to their deaf child [9]. Research by AlShammari *et al*. [10] indicates that when the parents of a deaf child are also deaf, they find it significantly easier to acquire sign language. In other instances, families may need to engage a specialized instructor for sign language education or enroll their child in paid classes, which can pose challenges regarding location, timing, and financial implications. Furthermore, if deaf children do not acquire proficiency in sign language at an early age, they encounter challenges in developing reading skills, education, communication, and societal interaction [11].

Addressing these gaps is important for promoting inclusive education and ensuring that students with hearing impairments achieve learning outcomes equivalent to their hearing peers. Integrating well-designed mobile applications into the educational process can augment accessibility, promote independent learning, and improve social adaptation.

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As highlighted in the research by Cabanillas-Carbonell *et al*. [12], the implementation of various pedagogical approaches and assistive technologies is essential for students with hearing impairments or deafness, as it facilitates equitable access to knowledge and skill acquisition comparable to that of their hearing peers.

According to Katsaris *et al*. [13], selecting an appropriate teaching method for developing applications for hearing-impaired students requires careful consideration of linguistic factors and a thorough evaluation of the learner's compatibility with the chosen instructional approach. Thus, the incorporation of mobile applications into the learning process for hearing-impaired children signifies a substantial progression in inclusive education.

The study aims to design, develop, and evaluate an educational mobile application specifically tailored to the educational and social needs of children with hearing impairments. The application is intended to facilitate effective learning of programming concepts, improve algorithmic thinking, and promote inclusion within the educational setting.

In accordance with the aim of this study, the following research questions (RQs) were formulated:

RQ1: Does the use of the educational mobile application positively influence the development of algorithmic thinking in children with hearing impairments?

RQ2: How does the use of the mobile application affect the academic performance of children with hearing impairments compared to traditional instructional methods?

Answering these questions will facilitate the assessment of the pedagogical importance of incorporating digital tools into the educational experiences of learners with Special Educational Needs (SEN). Moreover, the findings will assess the distinct impact of the developed application on improving the quality of knowledge acquisition. The results may also provide a basis for further adapting digital educational materials, considering the cognitive and communicative needs of hearing-impaired children.

II. Literature Review

A. The Role of Mobile Applications in Inclusive Education

One of the most promising approaches in supporting children with hearing impairments is the implementation of mobile applications that provide access to educational content, enhance communication skills, foster social integration, and improve digital literacy. Over the past decade, mobile technologies have evolved into powerful educational tools and have been increasingly applied to address the specific needs of this group of learners.

Previous studies consistently emphasize the significance of mobile devices in improving accessibility, flexibility, and personalization for hearing-impaired children. For example, Hashim *et al*. [4] emphasize the importance of appealing design features in maintaining engagement, while DeForte *et al*. [5] show that visual explanations and textual prompts significantly improve literacy outcomes. Collectively, these findings indicate that accessibility alone is inadequate; successful applications must incorporate usability, motivation, and curricular alignment to achieve significant learning outcomes. This integrative perspective guided the design of our application, combining accessibility features with structured programming instruction.

These digital tools facilitate the customization of the learning process to meet the unique needs of each student. This aspect is particularly important for hearing-impaired children, who may face challenges when relying solely on auditory or audiovisual materials. A mobile application designed for programming instruction may incorporate features such as video lessons with subtitles and sign language interpretation, visualizations, customizable text formats, and haptic feedback. Moreover, the utilization of interactive activities, visual coding blocks, game-based mechanics, and social features like competitions can augment programming skills, foster peer interaction, and enhance social engagement [14].

The potential of such tools was demonstrated in a study by Khasawneh [15], which examined the role of educational robots in fostering programming skills among elementary school students with hearing impairments. The findings indicate that instructional applications can facilitate skill development; however, their efficacy is significantly contingent upon teachers' prior training.

B. Existing Applications Designed for Children with Hearing Impairments

In recent years, numerous domestic platforms, mobile applications, and digital dictionaries have been created to promote inclusive education for hearing-impaired children. For instance, the AI-YM platform is an invaluable resource for promoting sign language, rendering it accessible to both individuals with hearing impairments and those interested in learning it. This fosters intercultural comprehension and enhances societal communication [16].

Another contribution is the e-Ymdau video dictionary of sign language, launched by the National Scientific and Practical Center for the Development of Special and Inclusive Education. This dictionary was established to standardize sign language usage in Kazakhstan and developed with the active participation of proficient sign language interpreters and educators. The primary features include convenience, efficiency, mobility, and accessibility. Additionally, methodological guidelines have been developed for the incorporation of e-Ymdau into the educational framework of specialized schools, and these are currently being extensively applied [17].

In addition, Amangeldy *et al*. [18] have created an intelligent system for recognizing sign language. Such tools are particularly valuable in enabling children to acquire sign language and develop essential interaction skills for everyday life.

A comparative review of existing international mobile applications for hearing-impaired users revealed several key examples. Internationally, applications such as Yandex.Talk [19], Deaftawk [20], and Spread Signs [21] provide valuable resources for daily communication, translation, and vocabulary enhancement. Although these solutions enhance social interaction, they predominantly focus on communicative competence rather than academic achievement. This highlights a research gap: existing applications excel at supporting everyday communication, yet they rarely address subject-specific skills such as algorithmic thinking or programming. This study directly addresses the gap by integrating accessibility with discipline-specific pedagogy.

ASL Pocket Sign is a mobile application tailored for hearing-impaired individuals, featuring tasks, assessments, and games that facilitate enjoyable learning of sign language [22]. Hand Talk Translator, a hearing-impaired people translator app, enables individuals with hearing impairments to communicate effectively with others. By utilizing pre-designed templates, users can easily express their requests through synthesized speech, facilitating smoother interaction in various social settings [23].

While an increasing number of studies have investigated the role of mobile applications in assisting children with hearing impairments, the majority of current solutions focus on communication rather than subject-specific education. Numerous prevalent applications [16–23] prioritize sign language acquisition, text-to-speech translation, or dictionary functionalities. These tools significantly enhance daily communication and inclusion; however, they do not facilitate the development of academic skills such as algorithmic thinking or programming.

A smaller body of work has attempted to integrate educational content beyond communication. Khasawneh [15] examined the utilization of educational robots to enhance programming skills in hearing-impaired students, whereas Abuzinadah *et al*. [14] explored the use of avatars to facilitate programming instruction. However, these approaches depend strongly on teacher mediation and are often limited by technological complexity, which reduces their scalability. Although certain studies employed gamified tasks [6], their primary aim was to enhance motivation rather than to develop higher-order cognitive skills.

Although a variety of mobile applications have been developed to support children with hearing impairments, the majority of them primarily focus on communication, vocabulary learning, or sign-language acquisition rather than the development of higher-order cognitive skills. However, algorithmic thinking - the ability to decompose problems, recognize patterns, and construct step-by-step solutions - represents a fundamental component of programming and digital literacy. Recent studies have highlighted the importance of designing learning environments that promote computational or algorithmic thinking among deaf learners through inclusive and engaging methods. For instance, Kaewkamnerd *et al*. [24] demonstrated that a STEAM-based approach integrating visual programming tools can significantly enhance computational thinking among students with hearing impairments, while Hashim *et al*. [4] emphasized the necessity of enjoyable and accessible design features in mobile learning for deaf children. Similarly, Kim *et al*. [25] identified usability and inclusion as key factors influencing engagement and cognitive participation in assistive educational applications. Nevertheless, existing tools rarely combine these accessibility principles with structured instruction in algorithmic thinking or programming. Addressing this gap, the present study contributes an inclusive mobile application that integrates visual, textual, and game-based elements specifically designed to enhance algorithmic thinking in children with hearing impairments, thereby aligning accessibility with discipline-specific cognitive development.

Collectively, these findings indicate that the field still lacks in mobile applications that integrate accessibility features designed for hearing-impaired children (e.g., subtitles, visual prompts, simplified instructions) alongside focused support for the development of algorithmic thinking. This study advances prior work by designing an inclusive mobile application aligned with the informatics curriculum, featuring video lessons, visual supports, and interactive exercises, and by providing empirical evidence of its effectiveness through a pretest-posttest design. This research advances inclusive technology design and enriches the broader discourse on subject-oriented learning for students with special educational needs.

C. Technological Aspects of Mobile Application Development

The development of an educational mobile application for teaching programming to children with hearing impairments requires a carefully designed approach that prioritizes both accessibility and inclusivity. An effectively designed application must offer an intuitive interface enhanced with visual elements to ensure seamless user interaction. Furthermore, all visual prompts and navigation elements should be tailored to accommodate the particular needs of hearing-impaired children, ensuring clarity and ease of understanding [26].

Integrating rich media such as videos, animations, and graphics can greatly enhance the comprehension of learning materials. For this audience, visual and textual elements are particularly important in supporting retention and deep understanding [27]. Applications that integrate sign language into their design can provide interactive video lessons featuring a teacher or virtual avatar demonstrating signs, thus offering clear visual representations that enhance learning and retention [28].

Textual support, including subtitles and detailed descriptions, is equally crucial for ensuring that children can access all content in written form [29]. The incorporation of interactive games and exercises further boosts engagement, helping develop memory, attention, language skills, and cognitive abilities. This gamified approach transforms learning into an immersive experience, increasing motivation and reducing cognitive barriers [30].

D. Key Challenges in Mobile Application Development

Despite the evident advantages, the development of mobile applications for hearing-impaired children presents numerous challenges. A primary limitation is the dominance of English and Russian sign languages in most applications, which considerably diminishes their accessibility for users communicating in alternative languages or dialects [31].

Furthermore, although mobile applications can augment educational processes, they cannot entirely replace face-to-face instruction or conventional pedagogical methods. Instead, they should be considered supplementary tools designed to complement established teaching practices [32]. To be effective, these applications must offer a high degree of personalization, considering such variables as the degree of hearing loss, the learner's age, and their specific educational needs [33]. Addressing these factors is essential for ensuring that mobile technologies truly enhance inclusion rather than merely replicating generic teaching methods.

In conclusion, mobile applications represent a valuable resource for inclusive education, offering new opportunities for learning, communication, and social integration for hearing-impaired children. However, the successful implementation of the apps depends on a thoughtful design that addresses accessibility, personalization, and cultural diversity. In the future, continued advancements in mobile technology and its integration into educational systems are likely to play a critical role in both academic achievement and social adaptation of children.

III. MATERIALS AND METHODS

The primary objective of this study is twofold:

1) To design and develop an educational mobile application for teaching programming and fostering algorithmic thinking among children with hearing impairments.
2) To evaluate its technological functionality, educational benefits, and overall effectiveness in comparison with traditional instructional methods.

To achieve these objectives, an experimental research methodology was applied. The study is grounded in the principles of pedagogical inclusion, which aim to ensure equitable learning opportunities for all students within the educational environment.

The research was implemented in two main stages:

1) Development of an educational mobile application tailored to the needs of hearing-impaired children.
2) Experimental evaluation of the application's efficacy in real learning settings, focusing on its technological attributes and pedagogical value.

Core methodological considerations included personalization of the learning process, the use of accessible digital technologies, and the adaptation of instructional materials to reflect the specific perceptual modalities of hearing-impaired students.

A. Development of the Educational Mobile Application

The mobile application was developed using Agile methodology, progressing through four iterative phases: Analysis, Design, Implementation, and inclusive design principles to guarantee accessibility for children with hearing impairments.

During the *Analysis* phase, a needs-assessment survey was executed to guide the layout, structure, and content of the mobile application. The participants included 15 sixth-grade students from a Specialized Boarding School for hearing-impaired children, 15 parents, and 2 teachers directly engaged in their education.

The primary objective at this stage was to ensure that programming concepts could be introduced via game-based learning elements within the application. Responses were analyzed to extract key user requirements, which included:

- Ease of interface—intuitive navigation and accessibility;
- User-appropriate functionality—adaptation to users' skills and prior experience;
- Alignment with task complexity—matching activities to cognitive and educational levels;
- Optimized interactive content—clear, concise, and effective instructional and feedback messages;
- Interactive feedback mechanisms—enabling responsive and engaging user interaction.

In *Design* stage, interface layouts and detailed software requirements were developed. The educational content (video lessons with subtitles, interactive exercises, and animations) was created using the *ActivePresenter* platform and subsequently integrated into the application.

1) Technical implementation

The application was developed in Android Studio utilizing the Java programming language, ensuring compatibility with the Android operating system, the most prevalent among the target group. The user interface was designed with XML layouts in Android Studio and enhanced with multimedia content generated in ActivePresenter.

The overall architecture followed a three-tier model:

Presentation layer—user interface components, including visual icons, simplified navigation, and subtitles.

Application logic layer—developed in Java, managing interactive task logic, scoring algorithms, and real-time feedback.

Data layer—implemented with SQLite, allowing the storage of user progress, test scores, and session data locally on the device.

This hybrid approach combined the advantages of a multimedia authoring tool (ActivePresenter) with a robust development environment (Android Studio) to create an inclusive and technically reliable application. The application's architecture is illustrated in Fig. 1.

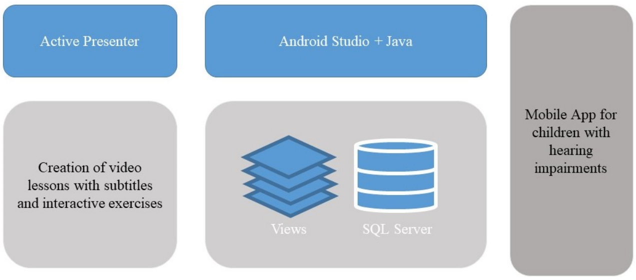


Fig. 1. Application architecture.

2) Description of the mobile application

The application comprised four instructional modules, each corresponding to Grade 6 informatics curriculum topics: sequences, branching, loops, and problem-solving. Each module included:

Instructional content: short video lessons with subtitles and highlighted visuals.

Interactive exercises: three types of activities (multiple-choice quizzes, drag-and-drop sequencing, and block-based mini-games).

Feedback mechanisms: immediate visual reinforcement for correct answers and guided hints for wrong responses.

Progression levels: sequential unlocking of modules, encouraging mastery and gradual skill development.

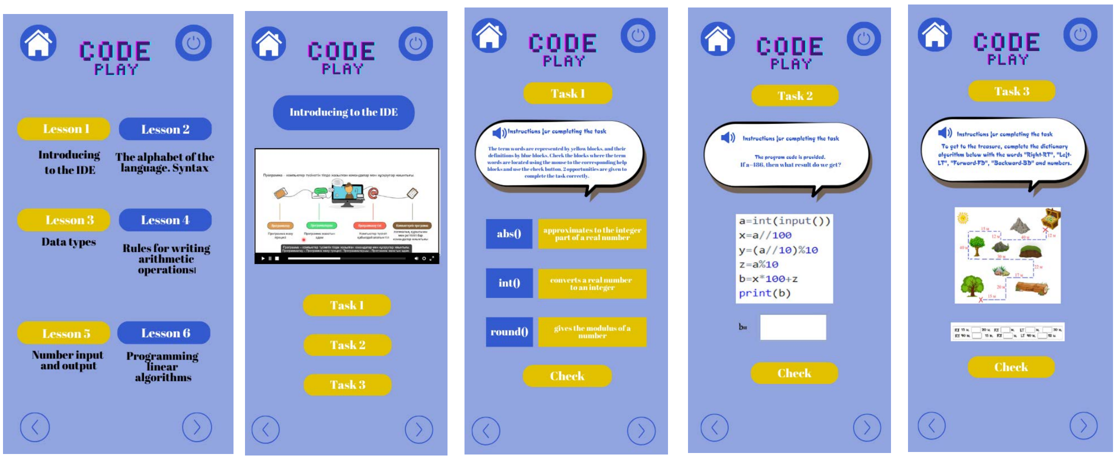
Accessibility features: simplified written instructions, visual prompts, and universal icons. Subtitles were integrated into all videos; additional sign-language support was provided by teachers when necessary.

This combination of structured learning content, adaptive feedback, and accessibility features made the application a suitable and inclusive tool for supporting algorithmic thinking among children with hearing impairments.

The external design of the mobile application prioritized accessibility for students, educators, and parents. The study emphasized usability and inclusive collaboration, enabling hearing-impaired children to participate fully in programming education.

The *Implementation* stage involved creating interactive prototypes and embedding functional code for essential interface elements, allowing for early demonstration and usability testing.

Fig. 2 illustrates the main components of the developed mobile application. As shown in Fig. 2(a), the content is directly aligned with the Grade 6 computer science curriculum, ensuring subject relevance. Each topic is introduced through short video tutorials with integrated subtitles (Fig. 2(b)), to accessibility for hearing-impaired users. The novelty of the application lies in the combination of accessibility features with curriculum-based programming instruction: three interactive game-based exercises per topic (Fig. 2(c–e)) support algorithmic thinking by incorporating block-based coding, algorithm compilation, code writing, and problem-solving tasks. The exercises are structured in sequential progression levels, enabling learners to access new modules only after mastering prior ones. Furthermore, the application integrates immediate feedback through animations, visual prompts, and guided hints, which reinforce correct answers and support learning in the event of mistakes. This combination of inclusive design, progressive gamification, and curriculum alignment makes the application distinct from existing sign language learning or communication-oriented mobile apps.



(a) (b) (c) (d) (e)

Fig. 2. Content of the mobile application.

In the Testing stage, the completed product underwent extensive testing involving both hearing-impaired children and their teachers. Evaluation criteria included structure and clarity of content, interactivity of exercises, functionality of assessment elements, ease of use, educational effectiveness, and overall system performance. Assessment ratings followed a four-point scale: Excellent (5), Good (4), Satisfactory (3), and Unsatisfactory (2). The obtained results are shown in Fig. 3.

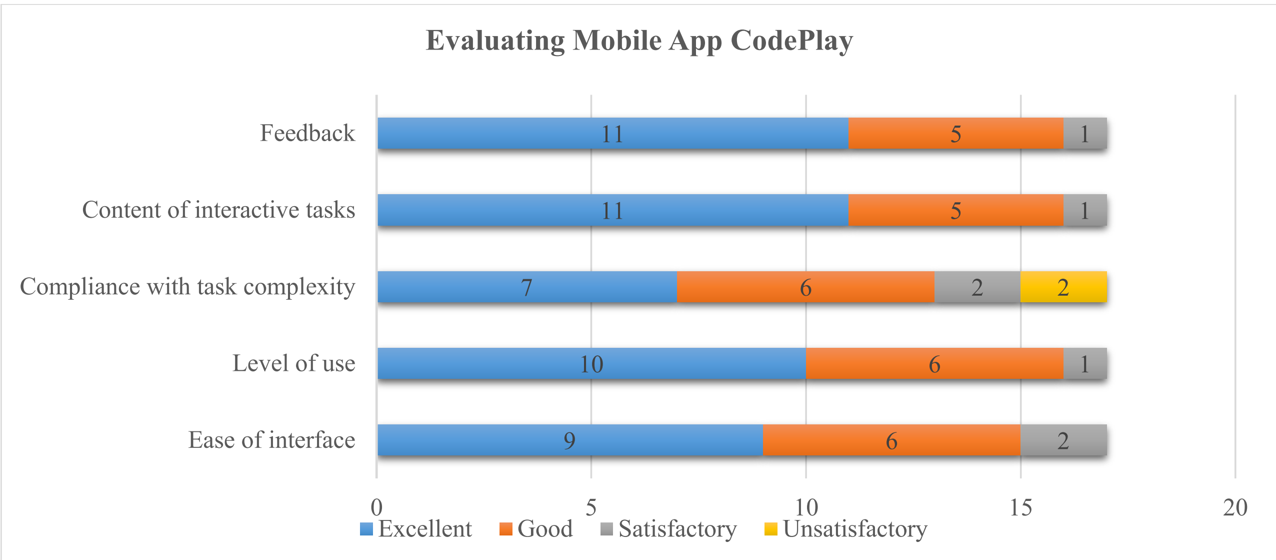


Fig. 3. Results of evaluating mobile App.

B. *Experimental Stage*

The experimental stage aimed to assess the impact of the mobile application on academic achievement.

The study involved 15 deaf students (8 boys, 7 girls) aged 12–13 years from a Special (Correctional) Boarding School.

All participants exhibited a similar average level of hearing impairment.

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A pretest–posttest control group design was implemented:

- Experimental group (n = 7): Used mobile application alongside core instructional materials.
- Control group (n = 8): Received the same content through traditional face-to-face instruction.

C. Assessment of Algorithmic Thinking

To assess algorithmic thinking in children with hearing impairments, we created a tailored paper-based assessment comprising 10 closed-ended and semi-visual questions aligned with the Grade 6 informatics curriculum. The assessment comprised tasks focused on pattern recognition, sequential problem-solving, and flowchart-based reasoning, thus minimizing dependence on complex verbal expressions. Each item was supplemented with visual diagrams, simplified written instructions, and universally recognizable symbols to enhance comprehension.

Content validity was confirmed via iterative expert evaluation: three subject-matter experts (two university faculty members in computer science education and one practicing special education teacher) independently assessed the clarity, cognitive suitability, and curricular alignment of each item. Their feedback led to amendments in task phrasing, difficulty levels, and visual aids.

A scoring rubric was clearly established to reduce subjectivity: each correct response was awarded 1 point, whereas incorrect or incomplete answers received 0 points. This binary scoring method produced a maximum possible score of 10, simplifying interpretation for both teachers and researchers.

Reliability of the instrument was verified through a pilot study with 10 students (not included in the main sample). The internal consistency analysis produced Cronbach's alpha = 0.69, which approaches the conventional threshold of 0.70. This value, though modest, is considered acceptable for exploratory studies in special education, especially when evaluating narrowly defined constructs with a limited number of items.

1) Procedure of the study

1) Informed Consent: Informed Consent: Informed consent was acquired from all individual participants in the study; teachers were introduced to the educational mobile application and given a demonstration of its features.
2) Orientation Week: The mobile application was installed on students' smartphones/tablets. Teachers guided initial navigation, including topic access, video lesson engagement, and exercise completion.
3) Pretest: Both groups completed an algorithmic thinking assessment.
4) Intervention (4 weeks): The experimental group utilized a mobile application, while the control group adhered to conventional teaching methods.
5) Posttest: Both groups repeated the same assessment to measure learning outcomes.

Table 1 shows procedure overview.

Table 1. Procedure overview

Phase	Step	Description
Preparation	Participant Selection	Sixth-grade students with hearing impairments divided into experimental and control groups.
	Development of Assessment Tools	Pretest and posttest created; validity checked by experts.
	Study Introduction	Participants briefed on objectives, procedures, and ethics.
Pretest	Initial Assessment	Baseline measurement of algorithmic thinking.
Intervention (4 weeks)	Experimental Group	Engaged with mobile application in guided lessons.
	Control Group	Learned via traditional instruction.
Posttest	Final Assessment	Same as pretest, measuring progress.
Analysis	Statistical Evaluation	Descriptive (mean, SD) and inferential (paired t-test) methods applied.
Conclusion	Reporting	Findings summarized, highlighting application's impact on learning outcomes.

IV. Results

The results prior to the experiment's implementation are summarized in Table 2, indicating that the established knowledge indicators for both the experimental and control groups were closely aligned. This initial balance between groups confirms that the comparison of outcomes is valid and that differences observed at later stages can be attributed to the intervention.

Table 2. Mean difference in experimental and control groups pre-test

Group	N	Mean	Standard Deviation
Control Group	8	**3.25**	0.90
Experimental Group	7	**3.14**	0.89

The post-experiment findings in Table 3 indicate that students in the experimental group exhibited markedly superior performance while utilizing the educational mobile application during the learning process, in contrast to their counterparts in the control group. A detailed comparison of the mean number of correct responses between the two groups during both phases of the study (Pretest and Posttest) indicates a significant enhancement in the experimental group. Their performance improved from an average of 3.14 correct responses in the pretest to 5.29 correct responses in the posttest. In contrast, the control group demonstrated minimal enhancement, with scores increasing from 3.25 to 3.5 correct responses. The results demonstrate substantial evidence of the efficacy of the educational mobile application that integrates game-based elements in enhancing student learning outcomes.

Table 3. Mean difference in experimental and control groups post-test

Group	N	Mean	Standard Deviation
Control Group	8	**3.50**	0.53
Experimental Group	7	**5.29**	0.76

The statistical analysis supports the conclusion. The Independent t-test results for the post-test, as shown in Table 4, reveal that the p-value was less than 0.05. This indicates that the improvement in the experimental group compared to the control group is statistically significant, thereby confirming that the use of the mobile application has a meaningful impact on the development of algorithmic thinking among hearing-impaired children. The computation of Cohen's d resulted in a value of 2.76, indicating a substantial effect size. The elevated value indicates that the educational mobile application significantly impacts the improvement of algorithmic thinking skills in the target group.

Table 4. Independent t-test of post-test

t-value	Statistic	df	p-value	Mean difference	Standard Error Difference	Cohen's d Effect Size
Student's t	5.3394	13.000	0.00013431	1.7857	0.33444	2.7634

Assumption testing indicated that the data were suitable for parametric analysis. Shapiro-Wilk tests indicated no violation of normality for the difference scores (experimental: $W = 0.96, p = 0.78$; control: $W = 0.95, p = 0.65$), and Levene's test confirmed homogeneity of variance ($F(1,13) = 1.12, p = 0.31$).

In the experimental group, posttest scores ($M = 5.29$, SD = 0.76) were significantly higher than pretest scores ($M = 3.14$, SD = 0.90), $t(6)=6.28$, $p < 0.001$, $d = 2.38$, 95% CI[1.36, 2.93]. The Wilcoxon signed-rank test confirmed this improvement ($T = 0, p = 0.02$). In contrast, the control group did not show significant improvements (Pre: $M = 3.25$, SD = 0.71; Post: $M = 3.50$, SD = 0.53), $t(7) = 1.53$, $p = 0.17$, $d = 0.54$, 95% CI[−0.13, 0.63]; Wilcoxon $p = 0.18$.

Between-group comparisons of gain scores demonstrated that the experimental group achieved significantly greater improvements ($\Delta M = 2.14$, SD = 0.90) than the control group ($\Delta M = 0.25$, SD = 0.46), $t(9.2) = 5.04$, $p < 0.001$, $d = 2.22$, 95% CI [1.07, 2.71].

Table 5 presents additional evidence indicating that the performance of students in the experimental group improved by approximately 30.7% as a result of their active engagement in game-based learning activities. This result highlights the efficiency of interactive methods in promoting knowledge acquisition when compared to traditional instructional approaches.

Table 5. Performance of students in the experimental group

Group	Pretest	Posttest
Experimental Group	44.8%	75.5%

V. Discussion

Beyond quantitative outcomes, mobile applications significantly enhance the accessibility of inclusive education for hearing-impaired children. The experiment findings confirm that integrating the mobile application into learning significantly enhances algorithmic thinking in hearing-impaired children.

Mobile applications also promote independent learning, enabling students to take greater control over their educational process, thus enhancing autonomy [34]. The integration of game-based elements has demonstrated an enhancement in engagement and motivation, rendering learning more interactive and enjoyable. This not only enhances active engagement but also facilitates the development of communication skills in a playful and immersive way [35]. Mobile applications can be customized to align with a student's developmental stage, personal traits, and particular requirements [36], thereby mitigating obstacles typically faced by children with hearing impairments in conventional classroom settings.

This study has several limitations that should be acknowledged. First, a major limitation of this study is the small sample size ($n = 15$). Small-N designs, though common in special education research, reduce statistical power and limit generalizability. The restricted sample size also increases sensitivity to individual differences among participants. Therefore, the findings should be interpreted as preliminary and exploratory. Replication with larger and more diverse cohorts across various institutions will be crucial to validate the robustness and external validity of the findings.

Second, the study relied on a single outcome measure - an algorithmic thinking test. Although this instrument provided valid and reliable evidence of learning progress, the absence of secondary indicators such as performance rubrics, behavioral log data, or teacher evaluations limited the triangulation of findings. Future studies should employ multiple complementary measures to capture a more comprehensive and multidimensional understanding of learning outcomes.

Third, lacking long-term follow-up limits conclusions on the sustainability of learning outcomes. While the post-test results indicate short-term improvements in algorithmic thinking, it remains unclear whether these effects persist over time. Future research should incorporate delayed post-tests or longitudinal designs to examine the retention and transfer of skills beyond the immediate intervention period.

These limitations suggest that the findings should be considered preliminary and exploratory. Future research should replicate the study with larger and more diverse samples and include additional outcome measures to further validate and extend the current findings.

In conclusion, the findings of this study demonstrate that mobile applications can play a vital role in enhancing both the educational and social adaptation of children with hearing impairments. Such tools not only contribute to the Fostering algorithmic thinking while also enhancing broader competencies such as communication skills, autonomy, and active engagement in the learning process. To enhance their efficacy, it is essential to consider cultural, linguistic, and individual student attributes while ensuring the continuous development and adaptation of mobile applications in line with advancing educational and technological standards.

VI. Conclusion

Educational mobile applications for hearing-impaired children are essential and promising instruments for enhancing inclusive education, as they markedly increase access to knowledge, foster the development of algorithmic and communication skills, and facilitate social integration [37]. The results of this study demonstrate that these applications not only promote academic success but also cultivate independence and confidence, thereby improving the overall quality of life for children with hearing loss.

The research has simultaneously identified several urgent challenges that must be resolved to optimize the educational and technological capabilities of mobile applications. The most urgent priorities are personalizing learning content for diverse cognitive, linguistic, and social profiles and developing adaptive mechanisms for different sign languages and cultural contexts. Another essential task is to ensure seamless integration of mobile learning tools with traditional teaching strategies, peer interaction, and teacher guidance, since these remain indispensable for the holistic development of communicative and social competencies.

Future research and development will focus on creating more intuitive user interfaces, employing intelligent algorithms for adaptive learning, and integrating multimodal resources that merge text, visual, and sign-language explanations [38]. Furthermore, it is essential to examine the long-term effects of mobile applications on academic achievement, cognitive development, and social integration, to formulate evidence-based strategies for sustainable implementation across various educational environments.

In conclusion, mobile applications demonstrate strong potential to transform inclusive education for children with hearing impairments. Advancing technological design, ensuring cultural and linguistic adaptability, and aligning digital tools with established pedagogical principles can significantly improve educational outcomes, foster socialization, and facilitate the complete integration of children with hearing impairments into society.

Ethical Statement

This study was reviewed and approved by the Ethics Committee of the Kazakh National Women's Teacher Training University (Protocol No. 5, dated 11 January 2025). All procedures involving human participants were conducted in accordance with the institutional guidelines and the national regulations governing educational research ethics in Kazakhstan. Informed consent was obtained from the parents or legal guardians of all participating children prior to data collection.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

G.S.—Project administration, supervision, funding acquisition, conducted the research, and wrote the original draft, review, and editing. A.M.—conducted the research, wrote the paper, curated the data, and analyzed the data; F. L.—conducted the research, wrote the paper, and provided visualization and resources. All authors had approved the final version.

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