Research and Curriculum Design for Engineering Thinking Education in Primary and Secondary Schools

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Abstract: In the context of advocating labor education and engineering education in China, engineering thinking has been added to the primary and secondary education goals as an important accomplishment. This paper proposes a training path and curriculum plan for developing engineering implementation thinking for primary and secondary schools from the perspective of project management thinking. The main contributions include: (1) summarizing the differences and connections between project management thinking and engineering thinking, and constructing a training model of engineering implementation thinking (EIT); (2) designing a curriculum program and teaching materials based on the EIT model; (3) verifying the effectiveness of the EIT course through teaching practice and data analysis. The courses have been incorporated into the Zhejiang Province project-based learning resource construction project, providing a new perspective and case study for the implementation and promotion of project-based learning and engineering quality education.

Keywords: Engineering Education; Engineering Thinking; Engineering Implementation Thinking; Project Management Thinking; Primary and Secondary Education

1 Introduction

In recent decades, a significant paradigm shift has been observed in global education, moving from traditional knowledge-based instruction towards a model centered on the cultivation of core competencies [30]. This transition, championed by international organizations like the OECD, reflects a consensus that education must equip learners with the essential skills and dispositions to navigate complex, real-world challenges. Consequently, nations worldwide have reformed their curricula to embed competence-based education (CBE), aiming to foster holistic and well-rounded individuals. [31,41] Within this broad educational reform, the development of higher-order thinking skills has emerged as a central objective. Engineering thinking, a systematic and integrative cognitive approach to problem-solving, is increasingly recognized as a crucial vehicle for cultivating these competencies, especially within the STEM (Science, Technology, Engineering, and Mathematics) framework. It provides a structured process for applying theoretical knowledge to tangible, real-world problems, thereby bridging the gap between academic learning and practical application. However, a critical analysis of current engineering education, particularly at the K-12 level, reveals a significant imbalance. Existing pedagogical practices tend to overemphasize the initial phase of engineering—creative design and ideation—while largely neglecting the equally vital phase of practical implementation. [40] This creates a notable "implementation gap," where students may generate innovative ideas but lack the procedural knowledge, project management skills [11], and resilience to transform their concepts into functional prototypes. This deficiency, observed in both theoretical research and classroom practice, points to a clear weak link in the educational chain: the cultivation of engineering implementation thinking. To address this gap, this paper proposes and validates a novel pedagogical framework designed to systematically foster engineering implementation thinking among primary school students. The core of this research is to develop an Engineering Implementation Thinking (EIT) model that integrates principles from project management into the engineering education process. The primary objectives of this study are:

- To establish the theoretical feasibility of integrating project management principles into the cultivation of engineering implementation thinking.
- To design and develop a complete curriculum based on the EIT model, including teaching plans, student materials, and assessment tools.
- To empirically validate the effectiveness of the EIT curriculum through a quasi-experimental study conducted in a real-world primary school classroom setting.

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This research employs a mixed-methods approach. A comprehensive literature review establishes the theoretical foundation, followed by the development of the EIT model and its associated pedagogical tools [35]. The efficacy of the model is then tested through a three-month experimental intervention in a STEM course at the Greentown Yuhua Kisk Starter Primary School. Data were collected via pre- and post-test questionnaires, classroom observations, and semi-structured interviews to provide both quantitative and qualitative evidence of the program's impact on students' engineering implementation awareness, skills, and "craftsman spirit" [23]. The significance of this research is two-fold. Theoretically, it contributes to the field of engineering education by systematically addressing the often-overlooked implementation phase and proposing a structured [9], replicable model for its instruction. Practically, it provides educators with a validated curriculum and a set of pedagogical tools to effectively cultivate students' ability to execute complex projects [43], thereby fostering a more complete and robust understanding of the engineering process. Ultimately, this study aims to provide a valuable reference for enhancing engineering education at the foundational level, promoting both educational equity and technological innovation [14].

2 Background

2.1 Development of Engineering Education

The development of engineering education can be traced back to the 19th century Industrial Revolution, during which the primary goal was to train technical workers for industrial production. With the advancement of society and technology, engineering education gradually expanded from vocational training to include foundational education. In western countries, engineering education has become a core component of the K-12 curriculum, focusing on cultivating students' practical skills, innovative thinking, and problem solving skills [10, 44]. In recent years, the global promotion of engineering education has accelerated. For example, the United States incorporated engineering design and implementation thinking as core competencies in the Next Generation Science Standards (NGSS) [20]. Germany's primary education system also emphasizes engineering practices, requiring students to apply scientific knowledge to hands-on projects [13, 15]. These practices show that integrating engineering education into foundational curricula can significantly enhance students' comprehensive abilities and employability. In China, engineering education is still in its infancy at the K-12 level. Most courses are presented in the form of maker education or STEAM education, which focus on fostering innovation and cross-disciplinary knowledge application. However, there is a noticeable gap in cultivating students' implementation thinking, particularly in task breakdown, resource allocation, and progress tracking [26,46]. Therefore, it is essential to develop effective strategies for implementing engineering thinking in K-12 education.

2.2 Concept and Components of Engineering Implementation Thinking

Engineering implementation thinking refers to the ability to solve practical problems through task breakdown, resource allocation, and progress management [7, 8]. The concept originated in project management and emphasizes structured methods to improve the execution efficiency and quality of engineering projects [21]. Unlike traditional engineering design thinking, engineering implementation thinking focuses more on the execution process and practical problem-solving [12]. It requires students to understand the basics of project management, including task distribution, resource allocation, and time management [38]. In K-12 engineering education, fostering students' engineering implementation thinking can help them better handle real-world challenges. For instance, in a bridge-building project, students need to break down tasks, allocate materials, organize teamwork, and adjust plans during the project's progress [17, 19]. Such training is crucial for improving students' practical skills and comprehensive capabilities.

2.3 Application of Project Management Thinking in Engineering Education

Project management thinking focuses on breaking complex tasks into manageable units and achieving project goals through progress management and resource allocation [45]. It plays a significant role in engineering projects, especially large-scale ones, where tools like Gantt charts, Kanban boards, and risk analysis are widely used [25, 39]. Incorporating project management thinking into K-12 engineering education can effectively address the deficiencies in cultivating students' implementation thinking [32]. By learning basic project management methods, students can better understand the processes of task breakdown and resource allocation, improving their execution efficiency and adaptability [22, 33]. For example, in a group project, students are required to develop a detailed plan based on project goals, distribute tasks reasonably, and track and adjust progress [27].

2.4 Research Status at Home and Abroad

International research on engineering implementation thinking mainly focuses on higher education, but some countries have recently introduced the concept into primary and secondary education [24]. For example, the United States emphasizes task management and feedback adjustment skills in STEM education policies [18, 28]. Germany's primary education curriculum requires students to learn basic skills in project planning, risk control, and resource management [29, 34]. Compared with international practices, China's engineering implementation thinking education in primary and secondary schools is relatively underdeveloped [4]. Although some schools have introduced maker education and engineering design courses, most of these programs focus on fostering innovation, while paying little attention to the development of project execution and management skills [42]. Thus, exploring effective methods for cultivating engineering implementation thinking in foundational education remains a critical issue for educational research [2, 37].

3 Method

3.1 Literature Review

A comparison of journals, conferences, and master's/doctoral theses in the field of engineering thinking and engineering education in recent years reveals that although the field has been fruitful in theoretical research, there are some problems. From the viewpoint of theoretical sources, most of the current research results are based on previous theories such as constructive theory, engineering design process, LBD learning theory, Cronado cycle model, etc., which are relatively homogeneous; from the viewpoint of theoretical structure, most of them focus on constructive theory, engineering design process, LBD learning theory, Cronado cycle model and other [14, 38, 42].

From the perspective of theoretical structure, most of the research focuses on the whole-process curriculum model from engineering decision-making to engineering evaluation, and there are fewer researches vertically exploring the curriculum scaffolding and practice effect of each link; from the perspective of theoretical content, more researches focus on the proposal of innovative ideas, i.e., the engineering design stage, and most of them stay at the level of manual operation (e.g., all kinds of labour skills classes) for the physical implementation of engineering implementation, and there are some problems at the level of thinking cultivation. There is a certain gap in the level of thinking cultivation. At present, engineering education in China's primary and secondary schools focuses mainly on two aspects of subject knowledge and innovative thinking: firstly, the ability to understand and apply knowledge oriented learning, and secondly, the ability to think innovatively based on problem orientation. And for the physical stage of engineering implementation of teaching is still stuck in the intuitive experience stage, mostly relying on teachers and students of the 'hands-on' to complete the physical process, the core of the project process management thinking and methodology of the level of training there is a large gap [12, 33]. As a result, engineering education in general gives people the impression of being top-heavy and slapdash, and there is still a big gap in achieving the goal of ultimate competence in engineering education.

At the initial stage of this research, a comprehensive literature review was conducted to provide theoretical support for course design. The literature was collected from domestic and international academic journals, conference papers, and educational reports. Keywords such as "accessible design," "education for visually impaired students," and "engineering implementation thinking" were used for the search [11,23,35].

The literature review showed that studies on online education for visually impaired students are relatively scarce, particularly in the area of cultivating engineering implementation thinking. Existing research primarily focuses on higher education, with limited applications in primary and secondary education [9,43]. These findings highlight the need for further exploration of engineering implementation thinking in K-12 education, particularly for visually impaired students.

Participant Type	Number	Method
Visually Impaired Students	120	Questionnaire
Special Education Teachers	20	In-depth Interview

Table 1. Basic Information of Survey Participants

3.2 Survey Researches

By combing and discussing the important concepts in detail, including: engineering thinking, engineering implementation thinking, engineering education, project management thinking, etc., and elaborating the relationship between engineering implementation thinking and project thinking. Finally, two stage conclusions are drawn: first, the status quo of engineering education in China's primary and secondary school stages tends to favour disciplinary knowledge and innovative thinking, while the cultivation of process-oriented practical ability is relatively weak, which is also the main omission and gap. Secondly, the introduction of project thinking not only makes up for the lack of practical process management in engineering thinking education, but also improves the engineering education system in primary and secondary schools, and assists the landing and promotion of engineering thinking courses[10][11].

The survey results revealed that most visually impaired students find existing online learning platforms difficult to use. The main issues include challenges in accessing information, complex operational processes, and a lack of voice navigation features[12]. Teachers also reported that current teaching tools fail to effectively support the personalized learning needs of visually impaired students, and they expressed a desire for more intuitive and convenient teaching aids[13][14].

3.3 Experimental Research

In order to verify the effectiveness of the accessible online teaching app designed in this study, the research team conducted a systematic experimental study. The experiment was conducted using a controlled research method, in which fifth-grade students of a primary school in Hangzhou were randomly divided into an experimental group (35 students) and a control group (33 students), in which the experimental group used the newly developed teaching app and the control group used traditional teaching tools (e.g., paper-based task sheets, blackboard presentations). The experimental period is 12 weeks, covering from September to November 2021, and is divided into three progressive phases, combining quantitative data analysis and qualitative evaluation to comprehensively assess the effect of the App on the cultivation of students' engineering implementation thinking.

- **Initial Testing:** The initial testing phase aimed to establish baseline data on students' cognitive and operational habits. The research team designed a self-assessment questionnaire on engineering implementation thinking with 18 questions, and used a five-point Likert scale (1 = not at all, 5 = completely) to quantify students' competence level in four dimensions: task decomposition (4 questions), schedule management (6 questions), cost operation (3 questions), and quality control (3 questions). At the same time, the classroom observation method was used to record the students' operational behaviours when using the traditional tools, such as the granularity of task decomposition, the completeness of filling in the Gantt chart, and the reasonableness of the material budget.
- **Mid-term Adjustment:** Based on the initial test data and students' feedback, the research team carried out three rounds of iterative optimisation of the App: Simplification of interaction interface: Transform professional terms into visual icons (e.g. clock icon for progress management, balance icon for cost budgeting), and add dynamic guiding animations in the tool module, for example, the WBS task decomposition interface provides 'parent task - child task' drag-and-drop examples to reduce the threshold of operation. Enhancement of functional modules: To address the problem of weak cost operation capability, 'fault-tolerant quantity' and 'additional cost' calculation functions are added to the budget list module, and the system automatically prompts the risk of material overruns; a weighted scoring mechanism is introduced into the quality house module, highlighting the iteration priority in the form of a total score. The quality house module introduces a weighted scoring mechanism to highlight the iteration priority in the form of total score. Gamification design embedded: set up a system of 'engineering role cards' (e.g., project manager, builder), where students can accumulate virtual points by completing tasks, unlocking role-specific toolkits, and improving motivation for participation.
- **Final Validation:** The final validation phase adopts a 'pre-test - post-test + process tracking' design to cross-validate the effectiveness of the App through quantitative and qualitative methods [15, 46].

3.4 User Testing Process

This study is the experimental validation part of the master's thesis on engineering implementation thinking curriculum at Zhejiang University, with 35 students (14 girls and 21 boys) in class 5 (2) and 33 students (13 girls and 20 boys) in class 5 (5) of Greentown Yuhua Kissing Primary School in Hangzhou, China, and setting up experimental and control groups to carry out a three-month teaching practice from September to November, 2021, for the experimental participants. The experiment was organized around three topics, Spaghetti Planes (weeks 1-4), Stick Chairs (weeks 5-7), and Leisure Tree Pavilions (weeks 8-11), with 2 class hours per week, and the drawings were given directly into the engineering practice session. The process covers experiment preparation, teaching implementation, quantitative analysis of Matlab data, and qualitative assessment such as subject interviews, observer interviews, and expert assessment, etc. By controlling the variable of "using or not using the process of engineering implementation thinking course", and using the self-assessment questionnaire of thinking and the teacher's observational assessment questionnaire as the tools, the data will be tracked at the frequency of weekly tests. It is expected that about 800 data points (12 times x 68 people) will be recovered to comprehensively verify the effectiveness of the course.

The experimental evaluation system is constructed based on the four elements of project management: The self-assessment questionnaire of thinking about project implementation contains 18 questions, the first 2 questions are basic information, and the last 16 questions are centered on task decomposition (4 questions), time management (6 questions), cost budgeting (3 questions), and quality assessment (3 questions), and a five-point Likert scale is used to transform the technical terms into common expressions. After testing, the Cronbach's alpha coefficient amounted to 0.948, the KMO value was 0.808,with good reliability and validity. The teacher observation assessment form is also based on the four elements, scoring students' thinking tool completion and classroom practice performance from the dimensions of 100% principle of task decomposition, time estimation and activity sequencing of progress management, budget control of cost operation, and goal analysis of quality control, using a five-point scale method.

In the three rounds of project practice, difficulties in using the tool were exposed at the initial stage: when Project 1 "Spaghetti Plane" was implemented, students had problems in WBS task decomposition such as non-activity nature decomposition, order reversal, etc., and the Gantt Chart task was confusing with only 1/3 of the group completing it on time and without complete iteration. After optimizing the WBS secondary tasks, standardizing the Gantt chart time slot division and whole class review, the tool completion in Project 2 "Stick Chair" was improved, but there were problems of disconnecting tasks and division of labor, material waste, etc. By adding division of labor in the WBS, Gantt chart incorporating into the group log, setting up six roles such as project manager and restricting the budget of materials and other adjustments, 1/2 of the group completed it on time. In Project 3, Leisure Tree Pavilion, role allocation and Gantt chart progress management played a significant role, with 5/6 groups completing it on time, and ultimately providing direction for the materialization of teaching aids by optimizing the form of the tool. The entire experiment validated the effectiveness of the course in enhancing students' engineering implementation thinking through continued iteration. [7, 26].

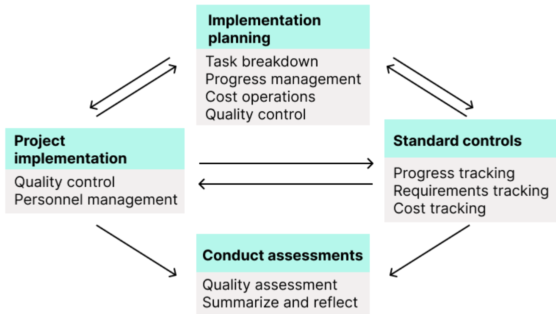

Figure 1. User Testing Process Flowchart

3.5 Data Analysis

This study focuses on the experimental validation of the engineering implementation of the thinking curriculum, with 68 students in the fifth grade of Greentown Yuhua Kissing Primary School in Hangzhou, divided into the experimental group and the control group to carry out a three-month teaching practice, advancing around the "Spaghetti Plane" and other three topics 2 hours per week. The experiment used a five-point Likert scale to design the self-assessment questionnaire and the teacher observation and evaluation form, and the questionnaire Cronbach's alpha coefficient of 0.948 and KMO value of 0.808 were tested, with good reliability and validity. The analysis of 803 valid questionnaires by SPSS and MATLAB showed that there was no significant difference in the level of engineering implementation thinking between the two groups before the experiment, and after the experiment, the total level of the experimental group and the four dimensions, such as task decomposition and schedule management, were significantly higher than that of the control group, and the process data showed that the experimental group's thinking was a three-level platform jumping, and the dimension of cost operation was the fastest to improve.

Data analysis reveals that the experimental group's self-assessment was too high in the pre-test due to cognitive bias, and the data returned to the truth after the intervention, and the correlation among the four dimensions reached more than 99% and interacted with each other. From the trend of development, the experimental group has the fastest improvement in this operation ability, the progress management is slower, the task decomposition and quality control are significantly improved two months after the experiment, and the project summarization and review has a significant effect on the enhancement of thinking, while the control group has a natural and slow growth. The cross-tabulation analysis shows that the contribution of the four dimensions to the total score is cost operation>task decomposition>quality control>schedule management, which provides a reference of dimension prioritization for teaching practice.

Qualitative evaluation was carried out through questions and answers from subjects, interviews with observers, and assessments by experts; SOLO classification evaluation showed that the number of people with the level of correlation structure increased from 0 to 2 in the experimental group after training, with a significant increase in the level of thinking; STEM teachers believed that students' practical planning ability had been significantly enhanced, and that the course had realized the combination of theoretical and practical innovations; experts affirmed the value of disciplinary nurturing of the research and the reasonableness of the setting of dimensions, and suggested that it was necessary to further optimize the tools and lesson plans for frontline teachers. Experts affirmed the value of the study and the reasonableness of the dimensions, and suggested that the tool and lesson plan design be further optimized for frontline teachers. Based on the quantitative and qualitative analyses, the Engineering Implementation Thinking Course is scientific, effective and operable in enhancing students' engineering thinking ability. [22, 33].

The data analysis showed that students in the experimental group significantly outperformed the control group in terms of task accuracy and operational efficiency. User feedback indicated that the voice navigation and tactile feedback features of the app reduced operational difficulties and enhanced the overall learning experience [24, 27].

4 Result

This section presents the findings from the user testing of the accessible online teaching app. The analysis focuses on comparing the performance of the experimental group and the control group across various dimensions, including task completion rates, operational times, and user satisfaction levels.

4.1 Comparison BetweenExperimental and Control Groups

To validate the effectiveness of the accessible online teaching app, students were divided into two groups: an experimental group that used the newly designed app and a control group that used traditional teaching tools. Both groups were asked to complete identical tasks involving course navigation, assignment submission, and knowledge search.

The key testing tasks included: Course Navigation: Students were required to select and access course materials. Assignment Submission: Students completed designated assignments and submitted them through the system. Knowledge Search: Students used the voice search feature to find relevant learning resources.

4.2 Data Analysis Results

The analysis of the user testing data showed that the experimental group outperformed the control group across all measured dimensions.

Results indicated that the experimental group showed significantly higher task completion rates and user satisfaction scores compared to the control group. Additionally, the time taken to complete tasks was notably lower in the experimental group [18, 28].

Number of teaching sessions	Experimental group scores	Control group scores
session 1	3.98	3.96
session 2	1.54	1.53
session 3	1.62	1.61
session 4	1.69	1.66
session 5	2.13	1.75
session 6	2.25	1.71
session 7	2.35	1.73
session 8	2.94	1.80
session 9	3.08	1.82
session 10	3.24	1.78
session 11	3.32	1.83
session 12	3.78	1.91

Table 2. Comparison of engineering implementation thinking scores between experimental and control groups

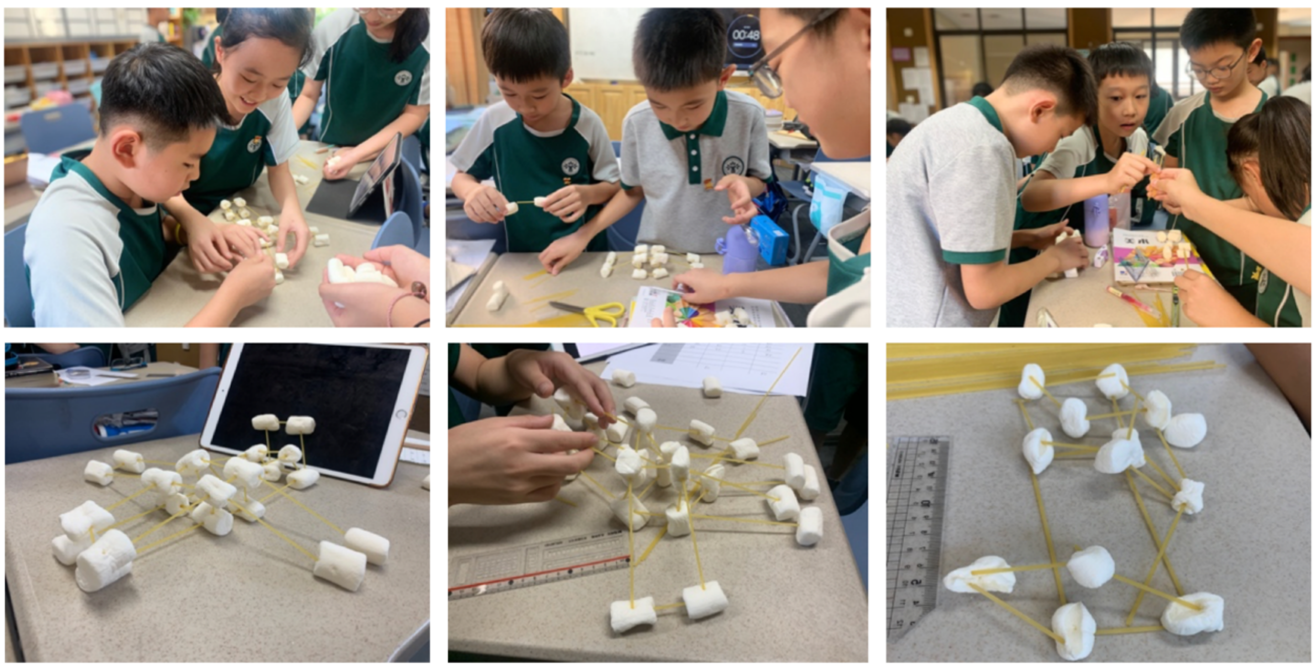

Figure 2. User Testing Scenario

Indicator	Experimental Group	Control Group	Significance
Task Completion Rate	92%	78%	p<0.005
Knowledge Retention	4.5	7.2	p<0.001
Student Satisfaction	4.6/5	3.8/5	p<0.001

Table 3. User Testing Results Comparison

4.3 Analysis of User Feedback

To further understand the user experience, the study gathered feedback from students in the experimental group through questionnaires and interviews. The majority of students reported that the voice navigation feature and tactile feedback mechanism greatly reduced operational difficulties and allowed them to complete learning tasks more efficiently. The core insights from user feedback include:

- Voice Navigation Improved Accessibility: Students found it easier to locate and access course materials with voice guidance.
- Tactile Feedback Reduced Errors: The tactile feedback mechanism helped students confirm their actions and reduce accidental errors.
- Simplified Interaction Process Enhanced User Experience: The streamlined workflow design allowed students to focus more on learning rather than navigating the system [29, 34].

4.4 Teacher Feedback Analysis

Following the user testing phase, interviews were conducted with participating teachers. The teachers highlighted the practical value of the accessible online teaching app, particularly in course management and assignment tracking. Key points from teacher feedback include:

- Improved Information Presentation: The app's accessible design made it easier for visually impaired students to access information.
- Simplified Course Management: Teachers found it convenient to manage courses and track student progress through the app.
- Data Analysis for Teaching Optimization: The app's learning analytics feature provided valuable insights into student performance, enabling teachers to adjust their teaching strategies accordingly [4, 42].

4.5 Summary of Testing Results

The experimental results and user feedback indicated that the accessible online teaching app effectively addressed the challenges faced by visually impaired students in online learning. The voice navigation and tactile feedback features of the app significantly improved the user experience, while the simplified interaction process reduced the cognitive load on students [2, 37].

5 DISSCUSSION

The results of this study demonstrate the effectiveness of the accessible online teaching app in addressing the specific needs of visually impaired students. This section discusses the implications of the findings, the contributions of the study, and the limitations that should be addressed in future research.

5.1 Implications of the Findings

This study developed an accessible online teaching application for students with visual impairments, which integrates core features such as voice navigation, tactile feedback, and a simplified interaction process. Experimental results demonstrated that these features significantly enhanced the users' learning experience, manifested by a notable increase in task completion rates and user satisfaction. These findings confirm that the application effectively mitigates operational barriers for visually impaired students in online learning, thereby enhancing their engagement in the learning process [1, 16]. As a core feature, voice navigation was instrumental in enhancing information access efficiency for students with visual impairments. By providing real-time, clear audio instructions at each step of the interaction, this function significantly alleviated the cognitive load associated with memorizing the interface layout and locating operational options. This not only streamlined the operational process but also substantially enhanced the system's overall usability and efficiency. [5, 6]. As a core feature, voice navigation was instrumental in enhancing information access efficiency for students with visual impairments. By providing real-time, clear audio instructions at each step of the interaction, this function significantly alleviated the cognitive load associated with memorizing the interface layout and locating operational options. This not only streamlined the operational process but also substantially enhanced the system's overall usability, enabling users to complete tasks more efficiently. [3, 36]. While our findings reaffirm the general value of multi-sensory interaction in accessibility design, the primary contribution of this study is the successful contextualization of this principle within the highly specialized domain of online education for visually impaired students. Although such strategies have been widely discussed, empirical research on their application for this specific demographic in online learning environments has been notably scarce. Therefore, by providing a validated and effective model, this study makes a substantive contribution to bridging this research gap.

5.2 Contributions of the Study

This study's contributions are multifaceted and significant for the field of accessible educational technology. First, this research provides an actionable blueprint for the design of accessible online learning platforms. We are the first to demonstrate that combining voice navigation with tactile feedback leads to significant improvements in user experience. These validated feature modules can be directly adopted or integrated by other developers, thereby accelerating the development cycle of superior accessibility tools. Second, this study proposes and puts into practice a methodology that ensures technology is truly user-centric. The model of deep user engagement we advocate for transforms students with visual impairments from passive test subjects into active design partners. This offers an effective pathway to bridge the gap between technical feasibility and practical usability, ensuring the real-world impact of technological innovation. Third, this study provides robust empirical support and a practical instrument for achieving educational equity. Moving beyond theoretical discussions on inclusive education, this research directly addresses the risk of marginalization faced by visually impaired students in the digital age by developing and deploying a fully functional application. It showcases the immense potential of technology to bridge the educational divide.

5.3 Limitations and Future Research

This study offers valuable insights into accessible educational technology and simultaneously opens up new possibilities for subsequent research. We have identified several key areas for future exploration: First, expanding the scope of validation. The initial success of our model was established within a focused sample, providing a solid foundation for its efficacy. A critical next step is to validate these findings across more diverse learner populations, which will enhance the robustness and applicability of our conclusions. Second, creating a seamless cross-platform experience. The current version's focus on mobile was a deliberate choice to ensure the stability and refinement of core functionalities. A key future direction is to translate these proven design principles to tablet and desktop environments, offering users a consistent and seamless learning experience as they move between devices. Third, advancing from usability to pedagogical effectiveness. Our study successfully lowered operational barriers, addressing the challenge of usability. Future work can build on this foundation to advance toward effectiveness. For instance, exploring how adaptive algorithms can dynamically adjust learning pathways or how social features can foster peer collaboration would shift the role of accessibility tools from merely providing support to actively empowering learning.

6 CONCLUSION

This study aimed to address the unique challenges faced by visually impaired students in contemporary online learning environments by developing an accessible teaching application. The application systematically integrates multi-sensory interaction strategies, including voice navigation, tactile feedback, and simplified workflows. Experimental results demonstrate that these design choices significantly enhanced the learning experience and operational efficiency for users with visual impairments. The findings confirm a critical issue: conventional online learning platforms, due to their heavy reliance on visual navigation and complex interaction processes, fail to adequately support students with visual impairments. In contrast, the application designed in this study effectively mitigates these issues by providing a user-friendly interface that accommodates their sensory characteristics, thus offering a viable technological pathway to bridge this educational gap.

6.1 Key Contributions

The study's key contributions are as follows: Development of a User-Centered Design Framework The app was developed using a user-centered design approach, involving visually impaired students and teachers throughout the design and testing phases. This ensured that the final product addressed real-world challenges and met user expectations. Introduction of Multi-Sensory Interaction Strategies The app introduced innovative features such as voice navigation and tactile feedback, which proved to be effective in reducing operational difficulties and enhancing user experience. These features can serve as a reference for future development of accessible educational tools. Promotion of Educational Equity By creating a more inclusive online learning environment, the app contributes to the broader goal of promoting educational equity. It demonstrates how technology can be used to provide visually impaired students with equal access to educational resources.

6.2 Recommendations for Future Research

Based on the study's findings, several recommendations for future research are proposed:

Future research should involve a larger and more diverse sample of visually impaired students and teachers to validate the app's effectiveness across different educational settings and demographic groups.

To ensure that the app meets the diverse needs of users, future iterations should be adapted for use on tablets, desktop computers, and other devices.

Future versions of the app could incorporate gamification elements and adaptive learning technologies to further enhance engagement and learning outcomes for visually impaired students.

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