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Research Article

Implementation of a Low-Cost, Real-Time Assessment System for Primary School Classrooms

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***Abstract*— The integration of technology in education has transitioned from being a supplemental enhancement to an essential element of modern teaching practices. Addressing this shift, there is a growing demand for cost-effective tools that boost student engagement and streamline assessment processes for primary students. This study introduces a low-cost, real-time assessment system designed specifically for primary school classrooms. The system, built using Arduino-based receivers, student-operated remote controllers and a test sofware, offers an affordable and scalable alternative to traditional student response systems. Field tests involving 26 students aged 9 to 10 at a public primary school demonstrated the system's effectiveness. Teachers observed significant improvements in student participation, focus, and enjoyment during assessments compared to traditional paper-based methods. Although challenges remain, the system shows great potential as a practical tool for resource-constrained educational environments, with future development aimed at enhancing scalability and resolving technical limitations.**

Index Terms— **Interactive learning, Real-time assessment system, Low-cost educational tools**

I. Introduction

THE INTEGRATION of technology into educational environments has shifted from being an optional enhancement to becoming a vital component of contemporary education [1, 2]. As primary education increasingly emphasizes formative assessments, the need for innovative digital tools that offer real-time feedback has become paramount [3]. Traditional paper-based assessments, while widely used, often result in delayed feedback, increased teacher workload, and limited interactivity, which can hinder timely support and student engagement in the learning process [4].

Student response systems (SRS) provide a promising avenue for addressing these challenges by enabling real-time interaction and immediate feedback for both students and teachers. These systems have been shown to enhance classroom engagement and improve learning outcomes by fostering active learning environments [5]. However, many SRS technologies remain prohibitively expensive and technically complex, particularly in educational settings with constrained budgets and limited technical expertise [6]. These barriers restrict the adoption of such tools in real-time learning environments [7].

The necessity for cost-effective, accessible, and affordable alternatives has driven the development of various open-source services and customizable solutions. This study introduces a novel approach with a low-cost, real-time assessment system tailored specifically for primary school classrooms. Leveraging a low-frequency 433 MHz communication system, this design overcomes many challenges of conventional SRS by offering an affordable and simple solution. Unlike Bluetooth or Wi-Fi-based technologies, this system eliminates compatibility and network dependency issues, making it particularly suitable for resource-constrained schools. Utilizing Arduino-based receivers and student-operated remote controllers, the system provides immediate insights into student performance, allowing teachers to dynamically adjust instruction based on real-time data.

Preliminary field tests in primary school environments have shown that this system significantly enhances student engagement, participation, and feedback processes. As education continues to evolve in the digital age, integrating such real-time assessment systems has the potential to transform classroom dynamics, reduce teacher workload, and improve student learning outcomes [8]. This study contributes to the literature by addressing the gap in affordable and accessible assessment tools for primary education. It also lays the groundwork for future studies aimed at optimizing and scaling such systems for broader applications, particularly in resource-constrained schools, while evaluating the system's effectiveness and exploring its potential for widespread implementation.

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II. RELATED WORKS

In recent years, Bluetooth and Wi-Fi technologies have emerged as prominent alternatives to traditional SRS systems. These wireless technologies offer faster data transmission and enhanced accuracy in tracking student responses. However, their cost and complexity often limit their use in primary school settings.

Swetha et al. [9] developed of a low-cost Classroom Response System (CRS) designed for large-scale adoption in developing countries, where expensive infrastructure like Wi-Fi is not always available. The proposed system utilizes Android platform and smartphones with Bluetooth connectivity, allowing instructors to gather student responses in real-time without the need for internet access. Experimental validation shows the system's feasibility, though it has limitations, such as potential impersonation and limited broadcast range. Also, it is not suitable for primary schools and the system requires a smart phone for every student.

Zualkernan [10] proposed a low-cost alternative by designing a CRS using an open source, easily manufactured hardware platform that incorporates both wireless and wired technologies. The system is designed for specific classroom environments with existing constraints. As such, it may not easily scale to larger or more technologically advanced classrooms without significant modifications. Also, the cost is higher than our proposed system.

Davidrajuh [11] introduced Bluetooth technology and its integration with Java to develop wireless applications. It then outlines a framework that identifies educational processes that can benefit from mobile technologies. The system relies on students and teachers having Bluetooth-enabled devices that are compatible with the application. This makes the system not suitable for primary schools.

Ibarra et al. [12] explored the development and implementation of an interactive learning system using mobile devices. It integrates ICT technologies with students' mobile phones to create a network that facilitates real-time data exchange between students and instructors. The system relies on students and teachers having mobile phone. This makes the system not suitable for primary schools.

Lu et al. [13] reports on a pilot study conducted in an English primary school using a Wireless Response System (WRS) developed at Huddersfield University. Although The system is costly, the findings indicate that the WRS was well-received by both students and teachers, with notable improvements in engagement and learning effectiveness across varying class sizes.

Alviar and Gamorez [14] explored the impact of using a Classroom Response System (CRS) in high school mathematics classes. Findings from the study showed that the CRS increased student engagement, interactivity, and was viewed as beneficial for learning.

Wu et al. [15] examined the effects of mobile-based Classroom Response Systems (CRS) on the learning experiences of graduate students in an entrepreneurship course. Students reported increased engagement, motivation, and improved capability in entrepreneurship, finding CRS particularly beneficial for learning in a flexible, interactive environment. The system requires mobile phones which is not suitable for primary students.

Although Bluetooth and Wi-Fi-based systems provide superior performance, reliability and application, their cost and complexity remain significant barriers for primary education. Besides using mobile phones is not suitable for primary students. The current study utilizes a low-frequency 433 MHz system as a more affordable solution, despite its limitations in handling multiple simultaneous responses and potential signal collisions.

III. MEDHODS

This section outlines the implementation and testing procedures for the low-cost, real-time assessment system developed for primary school classrooms. It details the hardware – software components and describes the approach used to evaluate the system's effectiveness.

A. *Participants*

The study was conducted in a primary school setting, involving 26 students aged 9 to 10 from a single class. Participants were selected from a public school in Kırsehir, Türkiye. The class teacher actively participated in the assessments, administering tests and providing feedback on the system's performance. The sample size was limited to 26 students due to the school management's decision to restrict testing to a single classroom. Ethical guidelines for educational research were strictly adhered to throughout the study.

B. *Procedure*

The study spanned three weeks, with assessments conducted in a controlled classroom environment. During each session, the teacher presented multiple-choice questions to the students via a smartboard. Students submitted their answers using remote controllers. Each session lasted approximately 15 minutes and included around 10 questions. The procedure for each session followed these steps:

- Initial Setup: The system hardware, previously introduced at a conference [16]. Figure 1 displays images of the hardware setup. Each remote controller has a unique identifier, as shown in Figure 1a. During the initial setup of the test program, each remote controller, uniquely identified by a specific number, was assigned to a student, corresponding to the class list. Figure 1b shows the Arduino-based device used to collect signals from the remote controllers. The teacher pre-selected the questions and uploaded them to the software's Test Tab before initializing the system.

Fig.1. The remote controllers used for selecting the correct answer and the central hardware

- Assessment: Students responded to questions by pressing the corresponding buttons on their remote controllers. The Arduino receiver collected and processed the responses in real time. Figure 2 presents a screenshot of the first test question displayed on the smartboard.

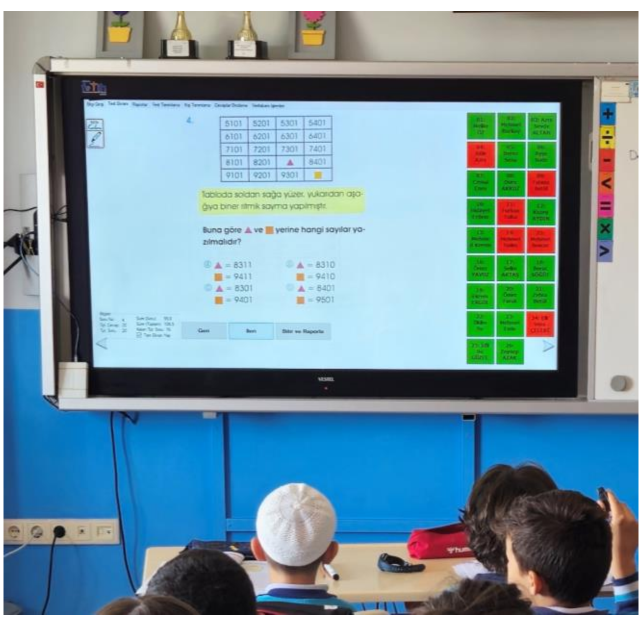

Fig.2. A screenshot of the first test question displayed on the test screen at the start of the assessment

- Feedback: The right panel of the test screen displays each student's first name and corresponding order number, aligned with the class list (Figure 2). When a student submits an answer, the color of their box changes from red to green. This provides immediate visual feedback on the smartboard, indicating which students have answered. Using this feedback enables the teacher to monitor participation and adjust timing as necessary.
- Post-Assessment: After each session, the system generated detailed reports for the teacher. The report offers insights into individual student performance, including the number of correct and incorrect answers, enabling the teacher to identify areas where further instruction may be needed. Figure 3 provides examples of reports generated after the completion of an assessment.

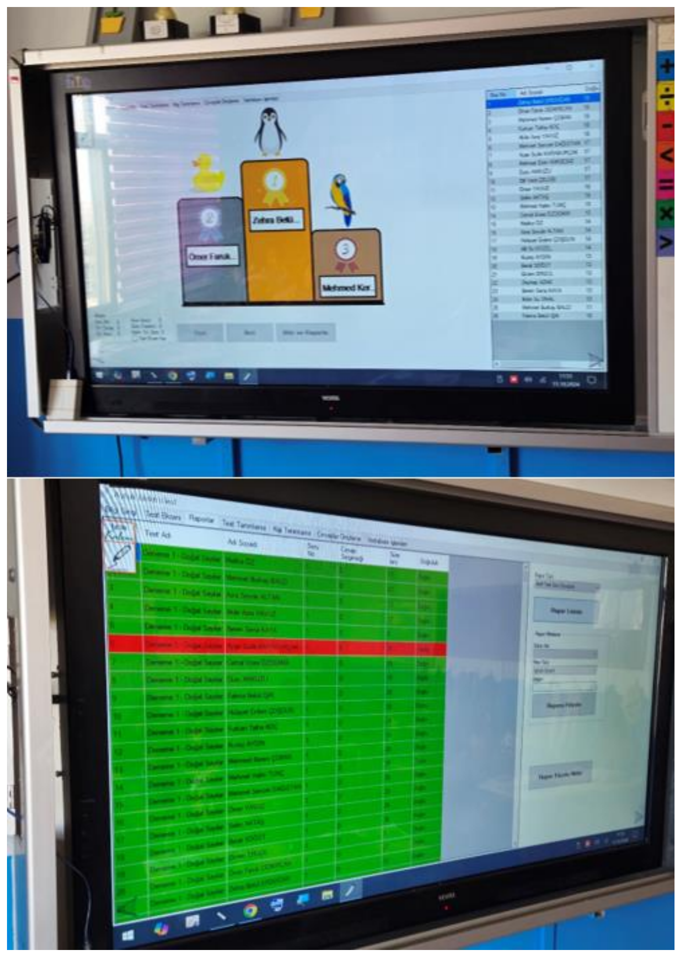

Fig.3. Screenshots from the test screen during an assessment

C. *Evaluation Metrics*

The effectiveness of the system was assessed through teacher observations, student feedback, and performance analysis. The evaluation focused on student engagement, system usability, and the efficiency of the assessment process. Key metrics are described below:

1) Observation Checklist for Teacher

- Participation rate: The number of students actively participating in answering questions using the system.
- Focus and attention: How engaged students appeared while interacting with the remote controls. Did they remain focused or appear distracted?
- Non-verbal cues: Observations of students' emotional responses, such as excitement, interest, or frustration during the activity.

2) Student Opinion Measured by the Teacher

The teacher collected student opinions using the following questions:

- How easy was it to use the remote controls?
- Did you enjoy using this system for the test?
- Did you find it more engaging than paper tests?
- Were you more focused during this test compared to others?
- Did you have fun while answering the questions?

3) Response Times Measured by The Teacher

The teacher measured how quickly the students completed the test using the system and compared these times to those from traditional paper-based tests.

D. Cost Analysis

The system was designed with affordability as a key consideration, ensuring its suitability for primary schools operating with limited budgets. The components were selected for their cost-effectiveness and availability. Table 1 presents a detailed breakdown of the hardware costs for a classroom of 26 students, including the Arduino-based receiver, remote controllers, and additional materials.

TABLE I
THE COST FOR A CLASS OF 26 STUDENTS

	Turkish Lira	**Dollar**
Arduino UNO	1000 ₺	$ 28.58
433 Receiver	70 ₺	$ 2.00
3D Printed box for Arduino	200 ₺	$ 5.71
3D Printed numbers for receivers	150 ₺	$ 4.29
Remote Controllers	2860 ₺	$ 81.71
Battery for the remote controllers	1300 ₺	$ 37.14
TOTAL	5.580 ₺	$ 159.43

This breakdown demonstrates the low-cost nature of the system compared to commercially available student response systems, making it a practical solution for schools with limited financial resources.

IV. RESULTS

Research evaluating primary education often emphasizes qualitative insights over quantitative results [17, 18], as the developmental variability of younger students can challenge the reliability of numerical data. Incorporating qualitative and developmental considerations is therefore essential for a holistic assessment in primary school settings. Consequently, this results chapter primarily focuses on qualitative findings to provide a nuanced understanding of the system's effectiveness.

Positive feedback from both students and the teacher, along with observed improvements in engagement and efficiency, suggests that this low-cost, real-time assessment tool is a highly effective alternative to traditional testing methods. The system not only maintained students' focus and increased participation but also made the testing experience more enjoyable. Additionally, the teacher noted that the system's real-time feedback and quicker response times facilitated more efficient assessments, enhancing classroom interaction and learning outcomes.

Participation Rate: The high participation rate observed during system use reflects a positive response from the students. The interactive nature of the system encouraged active engagement in the assessment process, resulting in higher participation levels compared to traditional methods.

Focus and Attention: Students remained focused and attentive while using the remote controls, demonstrating the system's ability to sustain engagement throughout the assessment. This is an important indicator of engagement, as students tend to lose focus more easily during traditional paper-based tests.

Time on Task: he system streamlined the assessment process, enabling students to respond quickly to questions. This is a reflection of the system's user-friendliness and the students' familiarity with the technology, which minimized delays in the response process.

Non-verbal Cues: The observations of excitement and interest, with minimal signs of frustration, demonstrate that the students found the system enjoyable and easy to use. This emotional engagement further supports the system's success in creating a positive learning and testing environment.

Ease of Use: The students consistently reported that the remote controls were easy to use, which is a critical factor for the system's success in a primary school setting. Simple and intuitive controls allowed students to navigate the system without difficulty, ensuring a smooth assessment experience.

Enjoyment: A majority of students expressed enjoyment in using the system for the test. This positive feedback suggests that the system's interactive design made assessments more engaging and less stressful than traditional methods.

Engagement Compared to Paper Tests: Students reported that the system was more engaging than paper-based tests. This finding is significant, as engagement directly influences motivation and learning outcomes, highlighting the system's potential to improve both participation and performance.

Focus: Students reported being more focused during the test, highlighting the system's ability to maintain their attention. This suggests that the real-time feedback and interactive components played a crucial role in enhancing concentration during the assessment.

Fun Factor: Many students described the experience as fun, emphasizing that the system not only functioned effectively as an assessment tool but also enhanced the overall testing experience.

The system's faster completion times, compared to traditional paper-based tests, further demonstrate its efficiency. The immediate nature of the system reduced the time required for students to answer questions, likely increasing engagement while reducing test-related anxiety. Faster response times also suggest that students felt more comfortable and confident using the system.

V. Discussion

The proposed system aligns closely with the principles of contemporary education systems, which prioritize formative assessments and active learning environments. Many national and international curriculums emphasize the importance of real-time feedback to enhance student outcomes and adapt teaching strategies dynamically. By enabling immediate assessment results and fostering engagement through interactive tools, the system directly supports these pedagogical goals. Additionally, its cost-effectiveness addresses the financial challenges faced by resource-constrained schools, ensuring accessibility without compromising educational quality. This alignment ensures that the system meets both technological requirements and practical needs, making it a valuable tool for modern, student-centered education.

The long-term potential of this system lies in its ability to transform classroom assessments by offering an accessible, scalable, and interactive platform. By streamlining the assessment process, the system reduces teacher workload, allowing educators to focus more on personalized instruction. Its capacity to enhance student engagement and motivation during assessments may contribute to improved learning outcomes over time. Moreover, the affordability of the system makes it particularly suitable for underfunded schools, paving the way for the broader adoption of digital tools in such environments. As future iterations address scalability and technical challenges, the system could be adapted for larger classrooms and diverse educational contexts, contributing to greater equity and inclusivity in education.

The system's applicability to other age groups depends on developmental and academic levels. For instance, it may not be suitable for first-grade students in primary school, as their motor and cognitive skills may not yet support effective use of the remote controllers [19]. Similarly, high school settings may present challenges due to the increased complexity of assessments. These considerations remain speculative, as empirical testing with other age groups has not been conducted. Future studies could explore modifications to the system to address these needs and extend its usability across broader educational levels.

The primary goal of this study was to design, implement, and evaluate a low-cost, real-time assessment system tailored for primary school classrooms. Feedback from both teachers and students indicated that the system effectively increased engagement and participation while providing real-time feedback to enhance the overall assessment experience. However, despite these positive outcomes, several limitations must be addressed, particularly regarding the use of the 433 MHz communication frequency and other potential challenges in practical applications.

The decision to utilize the 433 MHz frequency for communication between the remote controllers and the Arduino-based receiver was primarily motivated by the need for an affordable and user-friendly solution. However, the 433 MHz system has inherent limitations that could affect performance in certain classroom settings.

Signal Collision: A major drawback of the 433 MHz system is its susceptibility to signal collisions when multiple students respond simultaneously. Unlike advanced protocols such as Bluetooth or Wi-Fi, the 433 MHz system lacks pairing or identification mechanisms. As a result, simultaneous responses may lead to signal collisions, preventing some responses from being recorded. Although this issue did not significantly affect the results in this study due to staggered responses, it remains a potential challenge in larger classrooms or scenarios where multiple students respond at the very same time.

Limited Range and Interference: The 433 MHz frequency has a relatively short range and is vulnerable to interference from other devices operating on similar frequencies, such as wireless security systems or garage door openers [20]. In classroom settings, this could result in lost or delayed responses, especially if the receiver is not optimally placed or if the environment contains multiple sources of interference. Additionally, obstacles like walls or furniture in larger or more complex classroom layouts could further diminish signal reliability.

Lack of Encryption and Security: The 433 MHz communication protocol does not inherently support encryption, leaving the system potentially vulnerable to external interference or hacking [21]. While this is unlikely to pose a significant risk in a controlled classroom environment, it is a limitation that could become more relevant if the system were deployed in larger or more public environments, where malicious actors could interfere with the signal.

Scalability Issues: While the system performed effectively in a classroom of 26 students, its performance in larger classrooms remains uncertain. The current hardware may struggle to handle simultaneous input from a greater number of remote controls, particularly if signal collisions become more frequent.

Maintenance and Durability: While the system's hardware components were chosen for their affordability, the long-term durability of the remote controllers and the Arduino receiver remains a potential concern. In a primary school setting, where equipment is likely to undergo frequent use and potential mishandling, wear and tear could lead to malfunctioning devices. Additionally, the need to replace batteries in the remote controls or repair malfunctioning units could add maintenance costs over time, which might diminish the system's attractiveness for schools with limited budgets.

VI. FEATURE WORK

To mitigate the limitations associated with the 433 MHz system, future iterations of this assessment tool could incorporate more advanced communication protocols like Bluetooth or Wi-Fi, which offer better reliability, security, and the ability to handle multiple simultaneous inputs. But the trade-off between more advanced system and the cost must be adjusted carefully.

Future studies could also explore modifications to the system to address the specific needs of these age groups, expanding its usability and effectiveness across a broader range of educational levels.

Incorporating data analytics capabilities into the system could provide teachers with actionable insights into student performance. Features such as trend analysis, automatic grading, and personalized feedback would enhance the system's value as an educational tool.

Incorporating artificial intelligence (AI) to analyze assessment data could provide deeper insights into student performance and learning patterns. AI-driven analytics can identify trends, predict learning outcomes, and recommend personalized instructional strategies. This would enable teachers to better understand student needs and adapt their teaching approaches dynamically.

VII. CONCLUSION

This study presents a low-cost, real-time assessment system specifically designed for primary school classrooms. The system leverages a low-frequency 433 MHz communication protocol and Arduino-based receivers to provide an affordable, scalable, and interactive alternative to traditional student response systems. Field tests demonstrated that the system significantly enhanced student engagement, participation, and overall enjoyment during assessments, making it a promising tool for resource-constrained educational settings.

Despite its advantages, the system has limitations that must be addressed to maximize its effectiveness. Challenges such as signal collisions, limited range, and vulnerability to interference highlight the need for improvements in the communication protocol. Furthermore, scalability and durability concerns must be resolved to support larger classrooms and ensure the system's long-term usability. Addressing these technical limitations will be critical for broader adoption and sustained success.

The findings underscore the potential of this system to transform classroom assessment practices by reducing teacher workload, enhancing real-time feedback, and creating a more engaging and interactive learning environment. Future development should focus on optimizing the system for diverse educational contexts, including larger class sizes and varying age groups. Incorporating advanced communication protocols, improving hardware durability, and expanding usability will further enhance its appeal and applicability.

In conclusion, the proposed system offers a practical and effective solution for improving assessment processes in primary education, particularly in underfunded schools. With further refinement and development, it holds promise for contributing to greater equity and inclusivity in education, bridging technological gaps in resource-limited settings.

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Fahri ORMAN was born in 1965 in Kırşehir. He graduated from Selçuk University, Faculty of Education, specializing in primary school teaching. With over 30 years of experience as a teacher and 10 years as a headmaster, his entire life has been dedicated to his students in primary school. His interests focus on primary education and child development.