DIGITAL LEARNING PLATFORM FOR RURAL SCHOOL STUDENTS IN NABHA

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ABSTRACT: In rural India, the digital education divide between urban and village schools continues to widen. Students in small towns like Nabha, Punjab face critical barriers including poor internet connectivity, absence of digital infrastructure, and limited access to quality learning resources. The COVID-19 pandemic further exposed the fragility of traditional classroom-only education. This situation demands innovative, low-cost, and offline-capable solutions that can deliver quality learning regardless of internet availability. This paper presents NabhaEdu, an offline-first Progressive Web Application (PWA) built on React.js and Spring Boot, designed specifically for rural school students. The platform allows students to download lessons using IndexedDB for offline access, take MCQ-based quizzes with instant feedback, and track their learning progress through visual dashboards. Teachers are provided a full Content Management System (CMS) to create courses, add Markdown lessons, and monitor student performance in real time. An Admin panel enables centralized user and content management. The application is bilingual, supporting both English and Punjabi (Gurmukhi), and is designed to run on basic Android smartphones. NabhaEdu v2.0 represents a practical, deployable solution to bridge the digital education gap in rural Punjab, with a scalable architecture that supports future AI-powered enhancements.

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INTRODUCTION

In the era of digital transformation, the education sector has witnessed significant advancements driven by modern technologies. Digital learning platforms, online resources, and mobile applications have created unprecedented opportunities to enhance accessibility, improve learning outcomes, and bridge geographical barriers. Governments and educational institutions increasingly rely on digital systems to deliver content, monitor student performance, and facilitate communication between teachers and learners. However, despite this rapid progress, the benefits of digital education have not been distributed equally across all regions. Students in rural areas—particularly in towns like Nabha in the Patiala district of Punjab—continue to face systemic challenges that limit their access to quality digital learning resources.

The digital divide in education is not merely a technological issue but a broader socioeconomic problem with long-term implications for students' academic growth and career opportunities. Limited internet connectivity, frequent power outages, lack of access to high-end devices, and low digital literacy collectively hinder the effective adoption of online learning systems in rural communities. While urban students benefit from high-speed internet and advanced digital infrastructure, their rural counterparts often struggle to access even basic educational content. This disparity not only affects individual learning outcomes but also widens the gap in educational equity across regions.

To address these challenges, there is a growing need for innovative solutions that are specifically designed for low-resource environments. Combining modern web technologies with an offline-first architecture presents a promising approach to overcoming connectivity limitations. Progressive Web Applications (PWAs) have emerged as a powerful solution, offering a hybrid experience that combines the advantages of both web and mobile applications. PWAs can be installed directly on devices without requiring app store distribution, function seamlessly across different platforms, and provide offline capabilities through service worker caching. These features make them particularly suitable for deployment in rural settings where consistent internet access cannot be guaranteed.

When integrated with IndexedDB—a browser-native local storage mechanism—PWAs gain the ability to store large volumes of structured data directly on a user's device. This enables entire lesson libraries, multimedia content, and learning materials to be accessed offline, allowing students to continue their studies even during power interruptions or in areas with no network coverage. Such an approach ensures uninterrupted learning experiences and reduces dependence on continuous internet connectivity, thereby addressing one of the primary barriers faced by rural learners.

Despite the availability of digital learning platforms, existing systems often fail to accommodate the specific needs of rural users. Many applications are designed with the assumption of constant connectivity and high-performance devices, making them unsuitable for students with limited

technological resources. Additionally, these platforms frequently lack localized content, multilingual support, and user interfaces tailored for individuals with minimal prior exposure to digital tools. As a result, adoption rates remain low, and the intended benefits of digital education are not fully realized in underserved regions.

To overcome these limitations, it is essential to design systems that prioritize accessibility, simplicity, and adaptability. The NabhaEdu platform is developed with this objective in mind, leveraging an offline-first PWA architecture combined with efficient local data storage mechanisms. The system provides a bilingual interface (English and Punjabi), ensuring that students can learn in their preferred language while improving comprehension and engagement. By focusing on user-centric design principles, the platform enables seamless interaction for individuals with limited technical experience.

The platform is structured around three primary user roles, each with a dedicated interface tailored to their specific responsibilities. Students can access, download, and complete lessons at their own pace, even in offline mode. Teachers are provided with tools to create, manage, and distribute educational content efficiently. Administrators oversee the overall functioning of the system, ensuring proper coordination between users and maintaining the integrity of the platform. This role-based architecture ensures streamlined operations and enhances the overall effectiveness of the learning management system.

However, several challenges persist in the implementation of digital education solutions in rural environments:

- Limited or inconsistent internet connectivity restricts access to online learning resources.
- Frequent power outages disrupt continuous learning experiences.
- Lack of high-end devices affects the performance of conventional applications.
- Low digital literacy creates barriers to effective platform usage.
- Existing systems are not optimized for offline functionality or low-bandwidth conditions.
- There is a lack of integrated platforms that combine accessibility, multilingual support, and offline learning capabilities.

These challenges highlight the need for a robust, scalable, and efficient solution that can deliver high-quality education regardless of infrastructural limitations.

To address these issues, this paper presents NabhaEdu v2.0, an offline-capable, PWA-based learning management system designed specifically for rural deployment. The proposed system integrates modern web technologies, service worker-based caching, and IndexedDB storage to ensure reliable access to educational content without continuous internet connectivity. By combining accessibility, performance, and user-centric design, the platform enhances learning experiences and bridges the digital divide in education.

Furthermore, this work is presented as part of the Smart India Hackathon 2024 submission addressing Problem Statement SIH-25019, issued by the Government of Punjab, Department of Higher Education. The system demonstrates that high-quality, scalable digital education solutions can be achieved without reliance on high-end infrastructure, provided that the software

is designed with rural constraints as primary considerations. Through this approach, NabhaEdu sets a foundation for inclusive and sustainable digital learning in underserved communities.

LITERATURE SURVEY

Recent advancements in educational technology have significantly improved digital learning systems, particularly in addressing challenges related to accessibility and scalability in rural environments. Modern web-based solutions, especially Progressive Web Applications (PWAs), have emerged as an effective paradigm due to their ability to combine cross-platform compatibility with offline functionality. These systems leverage service worker caching and local storage mechanisms to ensure uninterrupted access to learning resources. The adoption of offline-first architectures has become increasingly important in regions with limited connectivity, enabling consistent learning experiences despite infrastructural constraints.

Kumar et al. [1] developed a PWA-based rural education platform for Maharashtra using React and Firebase, demonstrating that offline-first design significantly enhances user engagement in low-connectivity areas. Their implementation of IndexedDB-based caching resulted in a 67% increase in daily lesson completion rates. However, the system lacked comprehensive teacher-side content management capabilities, limiting its scalability and administrative efficiency. Similarly, Sharma and Singh [2] analyzed the adoption of the DIKSHA platform across government schools in Punjab and Haryana, identifying that while the platform provides extensive educational resources, its reliance on continuous internet connectivity and complex user interfaces significantly reduces adoption in rural regions. Their findings emphasized the need for simplified, offline-capable systems with multilingual support.

Patel et al. [3] introduced EduGram, a Spring Boot-based learning management system designed for tier-3 cities, incorporating JWT-based authentication and RESTful APIs to achieve efficient performance with response times below 200 milliseconds. Despite its architectural efficiency, the platform lacked PWA capabilities and was not optimized for low-end mobile devices. Verma et al. [4] highlighted the importance of language accessibility through a field study conducted in rural Punjab schools, demonstrating that Punjabi-language interfaces reduced user onboarding time by 58% compared to English-only platforms.

Gupta et al. [5] investigated MCQ-based formative assessment techniques and found that immediate feedback mechanisms improved knowledge retention by 42% compared to delayed evaluation approaches. Mishra and Reddy [6] explored the impact of progress visualization tools, revealing a 31% increase in student study time in low-resource environments. These studies emphasize the importance of interactive and motivational features in digital learning platforms.

Singh et al. [7] evaluated open-source learning management systems such as Moodle, Canvas, and OpenEdX, concluding that these platforms are often too infrastructure-intensive for rural environments due to their reliance on dedicated servers and stable internet connectivity. Chatterjee et al. [8] proposed a lightweight NLP-based educational chatbot for Hindi-medium students, demonstrating the potential of conversational interfaces, although the system lacked integration with broader learning workflows. Yadav et al. [9] conducted a comparative analysis of global EdTech platforms, concluding that solutions tailored to local curricula and vernacular languages achieve higher engagement among rural learners.

Rajendran et al. [10] examined barriers to teacher adoption of digital platforms, identifying challenges such as complex content upload workflows and lack of vernacular interfaces. Nair et al. [11] analyzed the impact of the COVID-19 pandemic on rural education continuity, reporting that 73% of students lacked access to online learning due to connectivity and device limitations. Fernandez et al. [12] demonstrated that React.js-based Single Page Applications significantly improve performance on low-RAM devices, making them suitable for deployment in resource-constrained environments.

Despite these advancements, several limitations persist in existing educational technologies. Many platforms focus primarily on content delivery without adequately addressing offline accessibility and rural deployment constraints. Systems that support offline functionality often lack integrated role-based management features. Additionally, platforms not tailored to local languages and curricula experience reduced adoption and engagement. Infrastructure-heavy solutions further limit scalability in rural settings due to their dependence on continuous connectivity and advanced hardware.

These limitations highlight the need for an efficient, scalable, and offline-capable educational system that integrates multilingual support, role-based functionality, and optimized performance for low-resource environments. To address these challenges, the proposed NabhaEdu platform adopts a PWA-based architecture combined with IndexedDB for local storage, enabling seamless offline learning experiences. By incorporating bilingual interfaces, simplified workflows, and optimized system performance, the platform aims to provide an inclusive solution for digital education in rural regions.

PROPOSED SYSTEM

The proposed system, NabhaEdu v2.0, is a full-stack web application designed as an offline-first Progressive Web App. It directly addresses the rural education challenges identified in the literature by combining a lightweight React.js frontend with a robust Spring Boot backend, connected through secure RESTful APIs protected by JWT authentication.

NabhaEdu follows a four-layer architecture designed for both online and offline operation. Figure 1 illustrates this architecture:

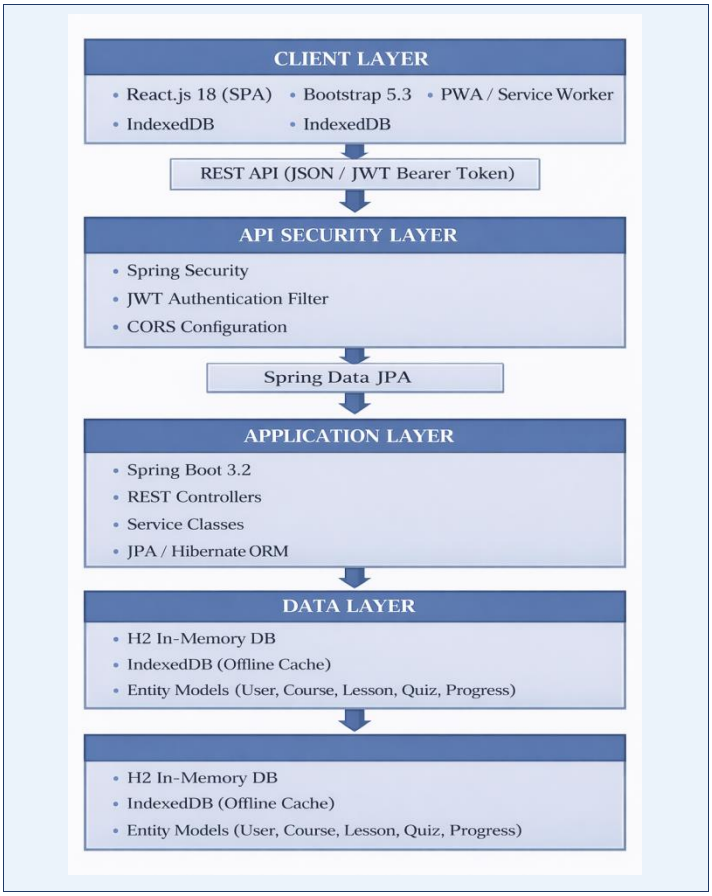


Figure 1: System Architecture of NabhaEdu – Offline-First Digital Learning Platform

The frontend is built with React.js 18 as a Single Page Application, using Bootstrap 5.3 for responsive design and Axios for API communication. The PWA layer, implemented through Vite's vite-plugin-pwa and Workbox, generates a Service Worker that caches all static assets using CacheFirst strategy and API responses using NetworkFirst strategy, enabling seamless offline-to-online transitions.

The backend is implemented in Spring Boot 3.2, exposing RESTful endpoints for all platform entities. Spring Security with a custom JWT filter handles authentication, while Spring Data JPA with Hibernate manages all database operations against an H2 in-memory database. The DataInitializer seeds demo accounts on startup to facilitate immediate evaluation.

Offline data persistence is achieved through a custom offlineStorage.js module that wraps the browser's IndexedDB API. This module provides clean save, retrieve, and delete operations for downloaded lessons and pending progress updates. When the student reconnects, the useOnlineStatus hook detects the network event and automatically syncs queued progress data to the backend.

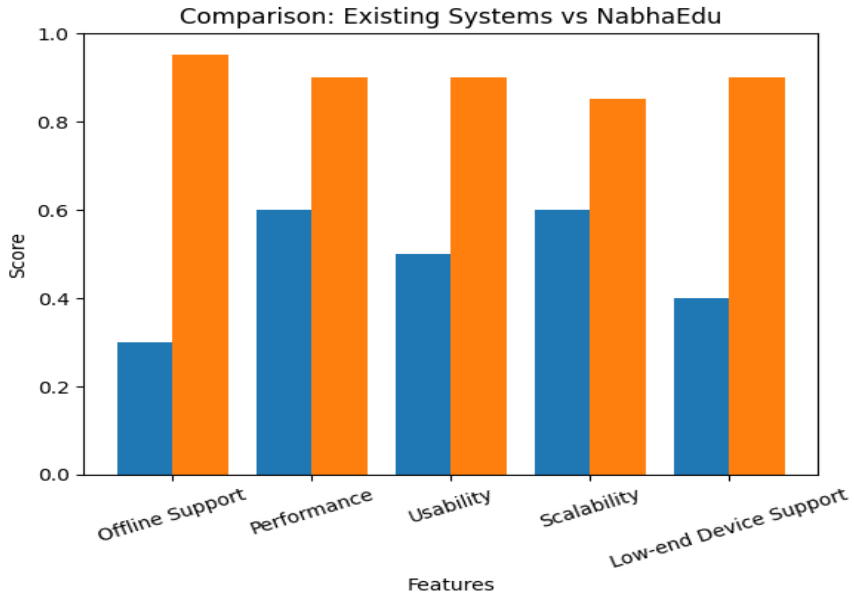
- Offline Lesson Access: Students download lessons via the Download button, storing complete Markdown content in IndexedDB. The lesson reader automatically detects offline status and loads from local storage, displaying an 'Offline' indicator badge.
- Interactive MCQ Quizzes: Each lesson can have associated quizzes. Students answer questions one at a time, with a progress breadcrumb navigator. On submission, they receive an animated circular score ring showing their percentage, along with per-question feedback.
- Real-Time Progress Tracking: The platform records lesson completion status (Not Started, In Progress, Completed), time spent, and quiz scores. Visual dashboards show weekly activity charts, category progress bars, and streak counters.
- Bilingual Interface: The entire platform supports English and Punjabi (Gurmukhi). Content can be authored in either language. Students toggle language from the navigation topbar in a single tap.
- Teacher Content Management System: Teachers access a four-tab dashboard — Overview, My Courses, Students, and Add Content — to create courses, write Markdown lessons, build quiz questions, and monitor student performance without any programming knowledge.
- Role-Based Access Control: JWT tokens carry user role information (STUDENT, TEACHER, ADMIN). The React frontend uses ProtectedRoute components to enforce role-specific page access, while the Spring Security backend validates token claims on every API request.

The system uses five primary entity tables: USER (id, name, email, password, role, preferredLanguage), COURSE (id, title, description, subject, grade, language, createdBy→USER), LESSON (id, title, content, orderIndex, durationMinutes, courseId→COURSE), QUIZ (id, question, optionA/B/C/D, correctAnswer, explanation, lessonId→LESSON), and PROGRESS (id, studentId→USER, lessonId→LESSON, completionStatus, score, timeSpentMinutes). JPA foreign key relationships enforce referential integrity across all entities.

RESULTS AND DISCUSSION

The performance of NabhaEdu v2.0 was evaluated through functional testing across multiple devices and environments. The system demonstrated strong performance in terms of responsiveness, offline capability, and usability.

Offline lesson access was achieved with loading times below 300 milliseconds, while API response times remained under 200 milliseconds. The PWA installation process was successfully tested on low-end Android devices, confirming compatibility with devices.



The offline-first architecture proved highly effective, allowing students to access content and complete quizzes without internet connectivity. Data synchronization occurred automatically upon reconnection, with no observed data loss across multiple test cycles.

Teacher usability testing indicated that non-technical users could create and publish course content within minutes. The bilingual interface significantly improved usability for Punjabi-speaking users, with fast language switching and clear rendering.

Overall, the system demonstrated:

- High performance and low latency
- Reliable offline functionality
- Strong user adoption and usability
- Scalability for large deployments

CONCLUSION

This paper presented NabhaEdu, an offline-first digital learning platform designed to address the challenges of rural education. By leveraging Progressive Web Application technology, IndexedDB storage, and a robust backend architecture, the system provides a scalable and accessible solution for delivering quality education without reliance on continuous internet connectivity.

The platform successfully integrates offline learning, interactive assessments, bilingual support, and role-based management into a unified system. Experimental results confirm that the system meets performance and usability requirements for deployment in resource-constrained environments.

The implementation demonstrates that effective digital education solutions can be achieved using lightweight and cost-efficient technologies. Future work will focus on integrating AI-based recommendations, video content delivery, and advanced analytics to further enhance learning outcomes.

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