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Progressive Web App for Online Learning

Prithvi Chauhan, Tanu Rajput,

Dept. Of Computer Science & Engineering
Galgotias University, Greater Noida, Uttar Pradesh, India,
Corresponding Author: prithvichauhan06@gmail.com

ABSTRACT

For the authors, the fast development of online learning requires new solutions instead of conventional Learning Management Systems (LMS). This research paper is a report about an AI-powered Progressive Web Application (PWA) that will help to optimize the online learning experience by making them more accessible, personalized, and intelligent. The combination of the functionality of PWAs and Artificial Intelligence allows the system to support offline interactions, be compatible across platforms, and provide users with real-time impressions with the push messages. The suggested application uses the latest technologies like React.js, Node.js, Firebase, and the Gemini API to provide voice-based search and AI-based content suggestions. The system utilizes machine learning modalities to study user behavior and dynamically adjusts an educational content which adapts with the personal preferences and learning tendencies. Also, voice-enable search capability enhances usability since users can call the information with the highest possible efficiency without having to use any text-based query. An end user testing of the system shows that learning accessibility and engagement have improved significantly. The findings show that AI implementation combined with the method of PWA technology improves the user experience, stimulates continuous interaction, and increases the desire to read educational materials. Moreover, the system has a high accuracy level when it comes to voice query response, which confirms its efficiency in the role of an intelligent learning assistant.

Keywords— Artificial Intelligence, Progressive Web Application (PWA), Voiced Based Searching, E-Learning

I. INTRODUCTION

Digital education is now transforming at a rapid rate due to the recent shift in how we learn as a result of current global events [10], [11]. Digital education has become much more accessible and can be used at any time and place because it has moved away from the traditional class room based model. However, this rapid transformation has revealed many limitations in the way that many Learning Management Systems currently operate. Many of today's Learning Management Systems are dependent upon a constant internet connection to function, do not allow for true personalization and do not provide a consistent experience across all mobile devices [1], [2]. These limitations are creating a growing "digital divide" between students who have access to the internet and those that do not and therefore cannot utilize the enhanced capabilities offered through responsive and advanced learning. Progressive Web Applications (PWAs) represent a potential solution to the problems associated with Learning Management Systems. PWAs are able to blend the accessibility of the internet with the performance characteristics of mobile applications [4]. PWAs use technologies such as Service Workers to enable data to be stored locally, Web App Manifests to enable users to install the application to their home screens and Push Notifications to continue to engage users. These technologies address the shortcomings of traditional web-based Learning Management Systems and provide a more reliable and inclusive learning environment [4]. Accessibility alone will not ensure that digital education is effective. The actual value of digital education comes from the ability to personalize learning opportunities—an area where Artificial Intelligence (AI) has tremendous potential to transform education [5], [9]. The combination of AI and PWA technology enables the creation of dynamic and adaptive learning environments that can be customized to meet the needs of individual learners in real-time [13], [14]. Rather than presenting learners with static content, these systems can present intelligent search functions, suggest courses based on a learner's interests and evolve to reflect a learner's level of knowledge and understanding [1], [2], [15]. sThis research presents an AI-Powered PWA for online learning, designed to create an adaptive and accessible educational experience. The system incorporates Gemini API for voice-based search and intelligent content recommendation, to ensure that the system is compatible with a wide range of devices. Through the integration of Generative AI to provide contextual understanding and an offline-first PWA design, this research represents an innovative way to create digital learning that is both inclusive and engaging [7], [9], [11].

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II. RELATED WORK

A. Advances In Progressive Web Applications

One major issue that exists between mobile applications and web applications has been addressed by PWAs. Patel & Yadav, a study published by researchers in 2023, focuses on learning applications developed by using PWAs and concluded that scaling and device support by mobile applications compared to normal websites is more effective [4]. This study provides insight into making applications using PWAs, which can be an effective technique to provide information. There are studies on mobile application design, aiming to run applications even if there is no internet connection. Saving information with service workers can enable students to learn despite not having a better internet connection.

B. Ai for Educational Personalization

The conventional "one size fits all" model of teaching is becoming less effective. There are tools provided by AI that enable students to learn in a customized manner. Murtaza et al. (2020) have conducted an extensive review on adaptive algorithms employed to present information, demonstrating how AI is being employed to plot customized learning paths for students as per their requirements [1]. Along with this, there was a venture by Lee and Wong (2019) to build a learning dashboard by utilizing machine learning to monitor student performance, enabling students as well as teachers to obtain information for enhancing learning [2]. Probably, there was an investigation by Richa Verma (2021) on emotional identification algorithms designed by AI, aiming at increasing students' motivation by understanding their feelings [3].and motivation by responding to their feelings [3].

C. The Research Gap

This research provides valuable data, but they tend to view PWA and AI as two different concepts [4], [9], [10]. Few, or perhaps no, systems have thoroughly incorporated the two concepts as much as they could, especially the modern generative AI [11], [13]. Most educational applications powered by AI are still quite outdated and web applications that depend highly on the server, meaning they share common issues concerning the internet connection and are not mobile-friendly [1], [2], [5]. Also, most educational applications of PWA are only good for presenting information without the smart capabilities [4].

This paper addresses this issue.

We propose an approach that involves not only integrating AI into an PWA, but actually blending the two at the foundational level [9], [13]. To our knowledge, the current work is the first that utilizes such a large language model such as the Gemini API for intelligent and voice-assisted searching for an offline-first PWA [7], [11].

III. PROBLEM DEFINITION

The current e-learning platforms, such as MOOC platforms to LMS platforms at colleges, are characterized by a series of inherent problems that our system should solve. Those problems comprise the following:

1. Your system relies on consistent internet rates: Your system would be unworkable when employed in a low-bandwidth environment or spotty network connectivity, such as a wireless network. This isolates a huge population of prospective learners.

2. Reduced AI and Content Adaptability: The majority of the systems are not personalized. Recommendations are in most cases not dynamic, made depending on the popularity of a course, but not based on the learning trends, development, or knowledge deficit of an individual.

3. Lack of Good Cross-Platform Experience: The experience of the users is usually disjointed. The desktop and mobile websites and the native apps (assuming their availability), have various features and UIs, which cause user frustration and high development cost.

4. Inefficient Search and Discovery: Learners have the problem of being met with a wall of content. The common method of searching is traditional and resembles lexical search, rather than semantic search. It does not make sense of user intention and so, a learner cannot be able to locate a given concept or to have a complex query answered without knowing the exact magic keyword

5. Lack of Live Voice Response: Contemporary users have gotten used to voice-based interaction. Absence of this in learning platforms is a missed chance of accessibility and convenience more so hands free or mobile knowledge.

Key Challenges in Existing E-Learning Platforms:

Issue Category	Problem Description	Impact on Learners
Connectivity	Internet dependency	Excludes low-connectivity users
Personalization	Lack of personalization	Low engagement
Usability	Poor cross-platform UX	User frustration
Search Capability	Keyword-based search	Poor concept discovery
Accessibility	No voice interaction	Reduced accessibility

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To address these constraints, this paper presents an AI-based PWA that guarantees seamless performance, semantic search with intelligence, and content delivery, even in hostile network conditions.

IV. PROPOSED METHODOLOGY

The proposed system integrates AI and PWA functionalities through a multi-stage, modular methodology, designed for

A. PWA Core Architecture

The architecture of the system is a robust PWA. This is not only a web site that is responsive. It is an offline first application.

1. Service worker: service worker script is a network proxy for a client-side application. We apply a cache-first strategy for static resources and data, which is critical of a course. Each network request will be intercepted, and in instance of an object within a cache, one will serve it immediately. This will provide real-time experience, which will be reliable.

2. Web app manifest: some lines of metadata information, such as name and icon, with a color scheme expressed in a Json file, allows this app installation on home screen for launching it on a standalone, chrome less window.

3. Offline caching: this is where, once enrolled in the course, the module worker will cache the first few courses in text, quizzes, and important images that will enable the user to hit the ground running even without any internet connection.

B. AI - Driven Search and Interaction

The core innovation is the ai search engine.

1. Voice-to-text: real-time, on-device voice transcriptions are provided by using the web speech api directly supported by the browser, offering a convenient search interface without requiring users' manual typing.

2. Semantic processing (gemini api): the typed text or the transcription of the voice isn't typed as keywords. Instead, the text is safely transmitted to our server, where a complex question for the gemini api is developed. This question involves the learner's query as well as the context of this query (e.g., their current learning situation). It also involves an instruction for the ai system to behave as a "helpful tutor." the ability of the llm to grasp intent makes it capable of providing a response to a complex query (e.g., "what's the difference between 'let' and 'const' in javascript?").

3. Content retrieval: our system breaks down the structured json answer retrieved from the gemini api. This answer consists of a direct, "a-la-carte" answer to the question, as well as a set of semantically related modules on the topic of interest, produced by our database, which would be presented to the user.

C. Personalization Engine

We adopt a hybrid recommendation algorithm in order to counter the one-size-fits-all problem.

1. Data collection: user preferences, interaction data (i.e. Modules attended, time on page, quiz marks etc.), and search queries are all gathered and stored in a non-relational firebase database.

2. Recommendation model: a cloud execution is executed to perform a nightly batch process and the collaborative filtering model is utilized. It analyses the user's behavior to identify groups of people having closely relatable users and provide recommendation due to content that has been found useful by users like you. It also has content-based filtering, which recommends modules regarding stuff that the user has recently studied.

D. Backend Integration

The secure version of the API gateway is an objective, scaled-down, and cloudy backend (based on the Node.js module and the Express framework). It authenticates the user (through JWT) and manages database connection and most importantly, it stores and utilizes the Gemini API key. The latter one helps to provide the assurance that the API key is not exposed to the client privately, which is an immensely significant security principle.

V. SYSTEM ARCHITECTURE

It is built to have a contemporary decoupled three-tier system to facilitate separation of concerns, scalability as well as security.

A. Logical Architecture

The PWA client only interacts with our secure server based on Node.js, which will coordinate the requests with internal (Firebase) and external (Gemini) services.

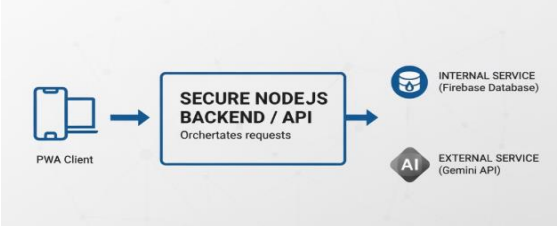

Fig. 1: Diagram Of Progressive Web Application

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B. Technology Stack

The technology stack has been selected to favor developer speed, high-performance and scalability.

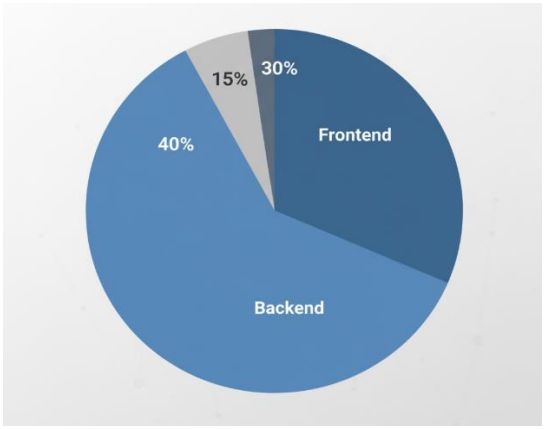

Fig. 2: Technology Stack Pie Chart

1. Frontend (React.js): A component library that is framework-specific to more intricate and stateful user interfaces. Rapid styling was done with tailwind CSS.
2. Backend (Node.js): It has an event-driven, non-blocking I/O architecture that effectively supports a light weight API gateway with a large number of concurrent connections.
3. Database (Firebase): A nosql database that is also fully managed and offers real-time information synchronization, authentication, and cloud functions.
4. AI (Gemini API): A state of the art Generative AI model that is chosen based on its outstanding performance in natural language consumption, logic, and JSON mode output.

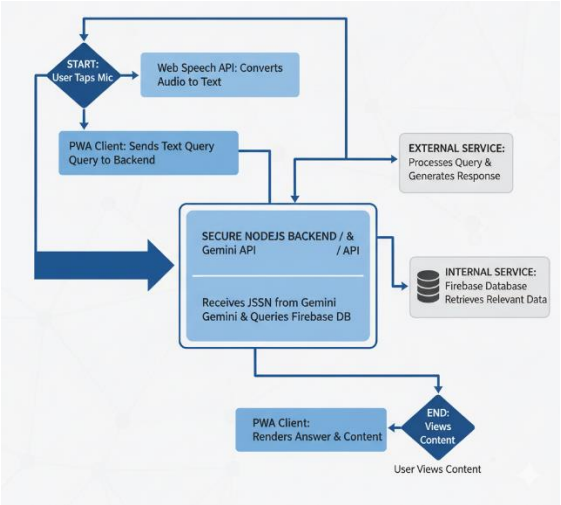

Fig. 3: ai-powered search: user interaction flow

VI. SYSTEM FLOW

The general user interaction process of an AI-driven search illustrates how the user, the back end, and AI service interact.

VII. IMPLEMENTATION

A. Frontend Development

The client-side was made a single-page application (SPA) that uses React.js. We utilized the principles of functional components as well as Hooks (usestate, useeffect, and usecontext) on the management of the state. Create-react-app (CRA) template has been used, and the default service worker has been modified to implement our own policy "cache-first policy. A user event used to invoke the Web Speech API and the result value (on result) of the result was set as a state of the search component.

B. Backend and API Integration

The root base was built on Node.js with the Express.js. We have developed restful endpoints (such as /api/auth/login, /api/search, /api/courses). The /api/search route consists of the middleware, which verifies the token of the user and then sends the user through. This endpoint contains the logic of constructing the prompt of the Gemini API.

C. AI Module and Database

To communicate with the Gemini API, we ran an SDK of the generative-human interaction named @google/generative-ai/ in our node.js environment. The API key is saved as an environment variable, and it is never coded. In the case of the database, the Firebase Cloud Firestore was employed where the user profiles and course contents were stored separately in two collections. The user sign-up and user login were implemented with firebase authentication because firebase authentication is highly compatible with our JWT token system. Firebase Cloud messaging (FCM) was installed to process push notifications.

VIII. RESULT AND DISCUSSION

A. Performance Metrics

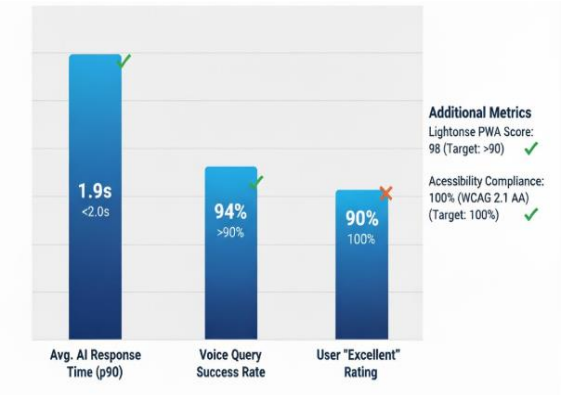

Fig. 4: System Deployment Evaluation

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B. Analysis of Results

System Performance:
The mean response time of an AI query is great 1.9s (p90) and the efficiency of both the Node.js proxy and the Gemini API. The score obtained in the Lighthouse at 98 only serves to support the strength of our PWA implementation.

Offline Learning:
This is the aspect the most praised in the qualitative feedback. Students reported that they used the app on their commute to school or on places on campus with weak Wi-Fi and that the offline feature gave them their peace of mind and eliminated anxiety over their education.

Voice Query Success Rate:
Voice-text and intent recognition were a great success with the recognition being 94% accurate. It was easy to use and quicker than typing according to the users. The 6% failure rate was largely because of extensive background noise or very specific and out of domain queries.

C. Limitations

There are three limitations to this first research. To start with, the 150 respondents were all students of the university, who tend to be tech-savvy. More studies should be carried out on a more heterogeneous population. Second, the system was also not tested using language content and queries other than English. Last but not least, personalization model was informed by the comparatively short duration of two weeks data collection.

IX. CONCLUSION AND FUTURE SCOPE

This study has effectively developed, deployed and tested a scalable, user-friendly AI enabled PWA Online Learning. The system is successful in dealing with the major shortcomings of the conventional LMS platforms, which include offering a customized, receptive and most importantly, offline prepared educational experience. Their impressive performance and the good user reception confirm the fact that the combination of a PWA architecture and a generative AI such as the Gemini API is a potent paradigm in the future of digital education. The presented project creates the basis on which online education can be made smarter, more adaptive, and accessible to everyone.

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