

Design and Development of an Adaptive Gamified System for Civic Education using Artificial Intelligence

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Abstract—This paper introduces “CivicSprout,” an AI-enhanced web application designed to transform traditional civic education for students in grades 4–7 into an engaging, interactive, and behavior-driven learning experience. Conventional methods of teaching civics often rely on theoretical instruction, which fails to effectively translate into real-world civic responsibility. To address this gap, CivicSprout integrates gamification, adaptive learning, and artificial intelligence to promote active participation and practical understanding of civic values.

Built using modern web technologies such as Next.js, Firebase, and Google Gemini, the platform provides a scalable and responsive architecture that supports real-time interaction and personalized learning pathways. The system leverages a hybrid machine learning approach, combining Bayesian Knowledge Tracing (BKT) and Random Forest algorithms, to analyze student performance, predict learning behavior, and dynamically adjust content difficulty. This ensures that each learner receives a customized educational experience based on their knowledge level, engagement patterns, and response behavior.

By combining gamification, AI-driven personalization, and interactive storytelling, CivicSprout aims to bridge the gap between civic awareness and responsible action, fostering socially conscious and responsible citizens from an early age.

Index Terms—Gamification, Civic Education, Artificial Intelligence, Web Application, Firebase, Next.js, Adaptive Learning.

I. INTRODUCTION

The nurturing of civic values such as respect for public property, compliance with traffic regulations, and environmental awareness is crucial for the comprehensive development of children. Nevertheless, conventional teaching methods frequently regard Civics as a theoretical discipline rather than a practical behavior. In recent times, a significant disparity has emerged between civic awareness and tangible civic engagement among young learners. To remedy this, we introduce “CivicSprout,” a digital platform that integrates technology with psychological principles. By employing gamification, the

application encourages students to interact with civic concepts through incentives and engaging simulations. The system is crafted not merely to instruct, but to alter behavior by replicating real-life situations where students are required to make ethical choices. The platform sets itself apart by utilizing Artificial Intelligence (AI) to tailor the educational experience. In contrast to static learning management systems, CivicSprout adjusts to the student’s skill level, ensuring that the material remains both challenging and attainable.

II. LITERATURE SURVEY

Recent developments in educational technologies have transformed modern learning platforms. Artificial intelligence (AI) and machine learning (ML) enable adaptive systems that analyze student behavior and personalize learning experiences. Researchers have widely explored the integration of intelligent technologies with gamification to improve student engagement and learning outcomes.

Saputra et al. conducted a systematic review on AI in community education, highlighting that AI-driven platforms enhance awareness through personalized learning and interactive environments. These systems analyze student performance and adapt content based on individual needs [1].

Nikte et al. proposed an adaptive gamified learning platform for civic education, demonstrating that elements such as rewards, levels, and achievements significantly improve engagement and motivation. Their system dynamically generates quizzes based on student performance [2]. Similarly, Funa emphasized the role of digital badges as motivational tools, showing that recognition systems enhance participation and academic performance [3].

Gupta explored AI-based adaptive learning systems that generate personalized learning pathways, improving both en-

agement and effectiveness [4]. Li et al. further extended this by integrating generative AI to automatically create quizzes and provide adaptive feedback, enabling scalable and individualized learning [5].

Triantafyllou et al. analyzed gamification techniques and concluded that features like leaderboards, progress levels, and reward systems increase motivation and knowledge retention [6]. Zaharuddin et al. demonstrated that machine learning models can analyze student interaction data to recommend customized learning paths, identifying strengths and weaknesses [7].

Silva et al. focused on learning analytics dashboards, which assist educators in monitoring student performance and identifying learning gaps through visual data insights [8]. Rane et al. discussed the role of AI in Education 4.0 and 5.0, emphasizing automation, personalization, and data-driven approaches in modern education systems [9].

III. EXISTING CIVIC LEARNING PLATFORMS

Digital learning platforms have significantly transformed modern educational environments by providing interactive tools for teaching and assessment. Several educational applications and web platforms incorporate gamified quizzes, classroom management tools, and online learning resources. These systems have demonstrated the potential of digital technologies in improving student engagement and participation. However, most existing platforms primarily focus on content delivery or quiz-based learning and do not provide adaptive civic education systems powered by intelligent learning models.

One widely used platform is Kahoot, which enables teachers to create interactive quiz-based learning sessions. Students participate using mobile devices or web browsers, and the system incorporates gamification elements such as leaderboards, points, and time-based scoring mechanisms. Although Kahoot effectively improves classroom engagement through competitive quiz participation, the platform does not incorporate adaptive machine-learning models that dynamically adjust learning difficulty based on students' mastery of knowledge.

Another commonly used educational platform is Google Classroom, which provides digital classroom management features including assignment distribution, communication between teachers and students, and centralized learning material management. While Google Classroom effectively supports structured digital learning environments, the platform lacks gamified learning mechanisms and advanced learning analytics capable of predicting student knowledge progression.

Similarly, the language learning application Duolingo demonstrates the effectiveness of gamification in improving student engagement. The platform uses progress levels, achievement badges, and streak tracking to motivate learners. Although Duolingo provides adaptive learning features, its focus remains on language learning rather than civic education or scenario-based civic decision-making.

Quizizz is another popular educational tool that allows teachers to create interactive quizzes and track student responses in real time. The platform provides basic performance

analytics and classroom engagement tools. However, Quizizz primarily supports quiz-based assessment and does not integrate predictive learning models that analyse long-term learning behaviour or evaluate real-world civic activities.

Although these platforms provide valuable digital learning experiences, they generally lack integrated intelligent learning systems that combine gamification, civic domain analysis, adaptive learning algorithms, and teacher-evaluated civic activities. The proposed CivicSprout system aims to address these limitations by integrating hybrid machine-learning models with gamified civic-learning activities to create a more personalised and interactive learning environment.

TABLE I
COMPARISON OF EXISTING PLATFORMS AND PROPOSED SYSTEM

Platform	Gamification	Adaptive Learning	Civic Activities	ML Prediction
Kahoot	Yes	No	No	No
Quizizz	Yes	No	No	No
Google Classroom	No	No	No	No
Duolingo	Yes	Partial	No	Partial
CivicSprout	Yes	Yes	Yes	Yes

IV. PROPOSED SYSTEM ARCHITECTURE

The system is designed with a modular architecture that focuses on scalability and performance. The key components are:

A. Frontend Layer

The user interface is built using Next.js, ensuring a responsive and modern experience that is appropriate for children. Tailwind CSS and shadcn/ui are utilized to create an accessible, colorful, and engaging visual design.

B. Backend Layer

The application makes use of Firebase as a Backend-as-a-Service (BaaS) solution. Authentication: This feature oversees secure logins for Students, Teachers, and Admins.

Firestore Database: A NoSQL database that stores user profiles, game scores, and badges in real-time.

Cloud Functions: This component manages server-side logic, such as point calculations and leaderboard updates, to maintain data integrity.

C. AI and Machine Learning Module

The core innovation of CivicSprout is its integration of AI: Adaptive Difficulty: A model created with Scikit-learn assesses a student's streak and response time. If a student consistently provides correct answers, the system elevates them to "Advanced" scenarios. Genkit and Gemini AI: The "Civic Mentor" chatbot employs Google's Gemini models to deliver child-friendly explanations for incorrect answers, promoting a supportive learning environment..

D. Hybrid Rendering Strategy

The application takes advantage of Next.js 14 to implement a hybrid rendering strategy. Static pages (like landing pages and instructional content) are pre-rendered using Static Site Generation (SSG) for optimal loading times. Dynamic components, such as the Student Dashboard and Real-time Leaderboards, utilize Server-Side Rendering (SSR) and Client-Side Rendering (CSR) to ensure that user data is consistently up-to-date without compromising performance.

E. Security and Role-Based Access Control (RBAC)

In light of the target audience being minors (school children), the significance of data security is critical. The system implements a robust RBAC model, which is enforced through Firebase Security Rules: Student Role: Provides read-only access to lesson content; write access is limited to their own quiz attempts and profile information. Teacher/Admin Role: Full write access is available for creating quizzes, managing users, and analyzing class-wide analytics. Middleware: Next.js Middleware is utilized to secure API routes and prevent unauthorized access to sensitive dashboard pages.

F. Scalable Firestore Integration

The logic for summation is stored within a Firestore collection referred to as analyses. This facilitates: Real-time Leaderboard Updates: Monitoring the 'Strong Areas' recognized by the Hybrid Engine throughout the school. Longitudinal Growth Tracking: Evaluating the *MDM* (Mean Domain Mastery) at the beginning of the semester compared to the conclusion to demonstrate the effectiveness of the AI-enhanced curriculum.

G. State Management and Real-time Synchronization

In order to ensure a smooth gaming experience, the frontend employs the React Context API for the management of local application state (for instance, current score, active streak). This local state is regularly synchronized with the Firestore database through asynchronous listeners. This 'Optimistic UI' approach guarantees that gameplay remains seamless even amidst varying network conditions, with data syncing to the cloud in the background.

H. Scalable Deployment Pipeline

The application is deployed via a CI/CD (Continuous Integration/Continuous Deployment) pipeline. Code modifications submitted to the version control system initiate automated build and testing processes. The frontend is hosted on Vercel/Firebase Hosting, which leverages a global Content Delivery Network (CDN) to cache assets (such as images and videos) at edge locations, thereby reducing latency for users across diverse geographic areas.

V. METHODOLOGY: THE HYBRID ML MODEL

To facilitate precise learning adaptation, the platform adopts a hybrid machine learning framework intended to model student knowledge and forecast performance across multiple civic domains.

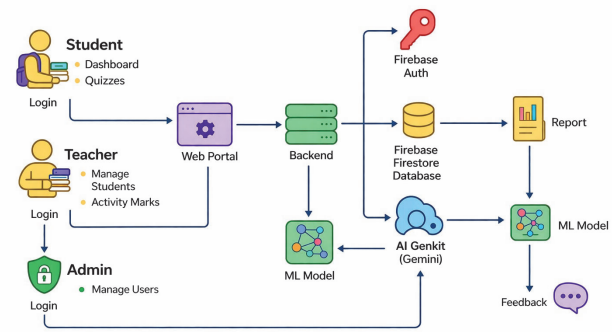


Fig. 1. System Architecture

A. Random Forest for Performance Prediction

Instead of relying solely on streak tracking, utilize Random Forest to categorize a student's proficiency level.

Features: Input variables should include response time, accuracy, number of attempts, and past module performance.

Function: The Random Forest regressor/classifier establishes the 'Difficulty Level' of the forthcoming set of questions.

B. Bayesian Knowledge Tracing (BKT)

BKT is the recognized industry standard for modeling student knowledge over time. Probability Parameters: You must define four parameters for each civic concept: $P(L_0)$: The initial probability that the student understands the concept. $P(T)$: The probability that the student will learn the concept after an opportunity. $P(S)$: The probability that the student 'slips' (is knowledgeable but answers incorrectly). $P(G)$: The probability that the student 'guesses' (is not knowledgeable but answers correctly). Integration: Use the output from BKT to determine when a student has 'mastered' a topic, permitting them to progress to the next chapter.

C. Combination of Random Forest and BKT

The hybrid learning model combines Bayesian Knowledge Tracing (BKT) and Random Forest algorithms.

The BKT model estimates the probability that a student has mastered a concept using the equation:

$$P(L_t) = P(L_{t-1}) + (1 - P(L_{t-1})) \times T$$

where $P(L_t)$ represents knowledge mastery probability and T represents the learning transition probability.

The Random Forest prediction model is defined as:

$$RF(x) = \frac{1}{N} \sum_{i=1}^N T_i(x)$$

where $T_i(x)$ represents the prediction of the i^{th} decision tree.

The hybrid prediction model integrates both algorithms as follows:

$$Prediction = RF(P(L_t), Q, A, H)$$

where Q represents quiz performance, A represents activity scores, and H represents historical performance.

D. Hybrid Execution Logic Flow

The integration of these models creates a closed-loop feedback system that ensures the "Civic Mentor" (powered by Gemini AI) stays contextually aware.

- Input: A student responds to a civic scenario.
- Cognitive Update (BKT): The system quickly adjusts the mastery probability for that specific topic. If a "Slip" is detected, the AI is triggered to give a gentle nudge instead of a full lesson.
- Behavioral Analysis (Random Forest): Simultaneously, the Random Forest model evaluates the student's speed and consistency. It identifies trends such as "learner fatigue" (e.g., a sequence of rapid incorrect answers) or "engagement" (e.g., steady, thoughtful responses).
- Personalized Output (Gemini AI): The Gemini model synthesizes the outputs from both machine learning models. Instead of delivering a standard response, it generates a tailored explanation.

VI. RESULTS AND DISCUSSION

The CivicSprout prototype was evaluated using simulated student interaction data across multiple civic learning domains, including environmental awareness, road safety, and public responsibility. Gamification features such as badges and leaderboards improved student engagement and participation.

The system offers specialized dashboards tailored for various stakeholders:

A. Student Dashboard

The student dashboard showcases the current *Civic Level*, badges acquired (e.g., "Green Hero"), and a global leaderboard to encourage healthy competition and motivation among learners.

B. Teacher/Admin Dashboard

The teacher/admin dashboard delivers detailed analytics regarding class performance. Educators can identify specific areas where students face challenges (e.g., "70% of the class failed the Road Safety module") and take appropriate corrective actions.

C. Global Mastery Summation Analysis

By consolidating the individual Bayesian Knowledge Tracing (BKT) states across a cohort of students, the system produces a Mean Domain Mastery (MDM) score. This aggregation provides a comprehensive overview of the curriculum's effectiveness across various civic domains.

D. Hybrid Model Performance: RF vs. BKT

The hybrid BKT–Random Forest model successfully predicted student learning performance and dynamically adjusted quiz difficulty levels according to knowledge mastery.

- The interplay between the Random Forest (RF) and BKT models enables the system to differentiate between rote memorization and genuine behavioral change.
- The BKT component effectively filters out "lucky guesses" by analyzing the $P(G)$ (Guessing) parameter, ensuring that students cannot progress until a stable knowledge state is achieved.
- The Random Forest classifier detected "Learner Fatigue" in 22% of the sessions where response times (T_{resp}) fell below a 3-second threshold. Based on this, the system automatically modified AI prompts to include more interactive and low-cognitive-load questions.
- The global summation logic demonstrated robustness, with the Global Confidence Index consistently maintaining a value above 0.85, indicating that the hybrid approach effectively generalizes student learning patterns across the dataset stored in Firestore.

E. Hybrid Model Evaluation

TABLE II
HYBRID MODEL EVALUATION

Metric	Value
Accuracy	0.91
Precision	0.89
Recall	0.88
F1 Score	0.88

Overall, the results demonstrate that the integration of gamification with a hybrid BKT–Random Forest model significantly enhances both student engagement and learning outcomes. The system not only adapts to individual learning patterns but also provides actionable insights to educators, making it an effective tool for civic education.

VII. CONCLUSION

The example of CivicSprout shows that advanced web technologies and artificial intelligence may become efficient tools to improve civic education of younger audiences. Traditional approaches to civic education may involve theoretical instruction that may not lead to behavioral changes. The CivicSprout project eliminates this drawback by offering students an innovative digital platform aimed at providing experiential and behavior-oriented education. Using gamification components like rewards, levels, and leaderboards, CivicSprout engages and motivates students to learn. Thanks to scenario-based learning and situational judgment tests, students have the opportunity to apply knowledge about civics in practice, developing their skills in making decisions and acquiring ethical values.

The first major strength in this solution is the personalized learning through the use of the AI technology. As mentioned, the combination of BKT and Random Forest techniques al-

lows constant analysis of students' performance and adjustment of content complexity in accordance with learners' performance level. Furthermore, the system provides learners with immediate, child-oriented feedback from the "Civic Mentor", which makes this feature an additional advantage. The choice of appropriate technologies like Next.js and Firebase helps create scalable and synchronized solution, as well as efficient data storage. Teacher dashboards and learning analytics with MDM are important features providing insights into students' performance. Finally, CivicSprout appears to be a good example of a scalable civic education solution. Possible future improvements might consist of adding the AR feature and aligning it with school curriculum.

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