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Academia: Design and Evaluation of a Low-Bandwidth RPG-Based Gamified Learning Platform

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Abstract: *However, unreliable internet connectivity, poor consumer devices, and the lack of engaging educational content have continued to limit the efficacy of e-learning in these regions in India. Existing solutions focus on facilitating high-speed connections and high-quality consumer devices, thereby limiting their efficiency in rural settings. Therefore, this gap limits quality education resources availability. In order to address this challenge, this research proposes Academia, which is an advanced gamified 2D tile-based RPG game designed specifically for children in the 6-12 age group in rural areas, focused on PCM.*

This platform will be implemented with Next.js 14 as the frontend web interface, together with Phaser 3 for 2D rendering capabilities. Unlike other solutions, Academia does not rely on either WebSocket or continuous polling for synchronization of states and the user interface. Instead, Academia uses a special State Bridge concept, which leverages the native CustomEvent capability available in browsers for synchronized communication with no or limited negative effect on game performance [1,2]. With Academia, critical player data such as health and experience points can be updated seamlessly.

As mentioned before, Academia incorporates a special learning method called "Tall Grass Practice -> Gym Boss Assessment," inspired by conventional RPG games. In this case, users' skills are improved randomly through multiple-choice questions. Once users gain enough experience points, they undergo Gym Boss assessment, which is basically a summative assessment. The experience points are computed using quadratic equations for equal progress. Player data and achievement details are stored in PostgreSQL databases in Supabase. Asynchronous synchronizations will help reduce network traffic. Preliminary evaluation suggests more engagement and consistency among rural learners with low bandwidth demands.

Keywords: Gamification, Role-Playing Game (RPG), E-Learning, Rural Education, STEM, Phaser 3, Next.js 14, Low-Bandwidth, PCM, Digital Divide, Supabase, State Bridge, Quadratic Leveling, CustomEvents, PostgreSQL

I. INTRODUCTION

A. Background and Motivation

The rapid proliferation of new and advanced digital technologies has led to the complete transformation of the global education industry during the last two decades. Virtual classroom systems, MOOCs, LMSes, and other intelligent tutoring systems have allowed students from urban areas to gain access to an immense amount of educational content. Online platforms like Coursera, Khan Academy, BYJU'S, and Unacademy attract millions of users from all over the globe thanks to high-quality video lectures, various interactive quizzes, and even personalized study programs provided by artificial intelligence [3].

Unfortunately, the development of technology-based education in today's world proved to be highly uneven in many aspects. Taking into account the semi-rural and rural population of India, a wide range of structural constraints still hinders any adoption of digital learning technologies by students from these regions. First of all, there is an issue of poor internet access in rural parts of developing countries where people rarely receive stable internet connections via 2G or very weak 4G networks that are prone to frequent outages. According to the UNESCO Global Education Monitoring Report [3], quite a large number of children from developing countries cannot access the internet due to the fact that urban areas have reached digital coverage.

Secondly, there is a problem of lacking appropriate devices. In cases where students from rural areas can actually get connected to the internet, they mostly resort to the use of low-end Android phones or old computers which have low performance capacities that are hardly sufficient to work with most modern web applications, including WebGL-enabled video, high-resolution images, or complex JavaScript. Therefore, despite the fact that students have the internet connection, many websites and platforms will prove to be unworkable due to poor performance issues [4].

The third aspect to consider relates to engagement. Although students from semi-rural or rural regions may succeed in accessing digital learning resources, the majority of platforms are passive-oriented. This means that they use pre-recorded lectures, static PDF documents, and simple quizzes. However, studies demonstrate that the effectiveness of passive methods in maintaining learners' attention and ensuring long-term information absorption is much lower than active methods, especially for abstract subjects like Physics, Chemistry, and Mathematics [1].

B. The Case for Gamification in Rural STEM Education

Gamification – the practice of applying design concepts and mechanics commonly associated with video games to applications outside of gaming and entertainment – has become one of the most interesting fields in education over the past decade [1]. Research by Deterding et al.

[1] provided a thorough conceptualization of what constitutes gamification, which, distinct from both games and toys, is defined as an intentional use of game-like mechanics to serve some external goal. Subsequent empirical studies carried out by Hamari et al. [2] confirmed the effectiveness of gamified systems in increasing users' engagement, motivation, and achievement via systematic review of the literature.

As far as education is concerned, gamification has been employed in various ways, ranging from implementing such basic practices as leaderboards and badges into the Learning Management System, to developing serious games. Nevertheless, most gamified educational tools today only employ gamification to motivate students while leaving learning process untouched. Reading materials, viewing video lectures, and taking quizzes are still what the students have to do to complete their assignments; however, doing all these actions earns them points. The result is a short-term spike in engagement, which subsides when the novelty of earning points goes away [2].

One feature that is strikingly missing from the current gamification research is the implementation of high-fidelity gamification. Specifically, it would mean integrating educational materials in a gamified system in such a way that engaging in gameplay means learning, and vice versa. In other words, learning and gaming would be combined, rather than merely being placed side-by-side. This project aims to fill the aforementioned gap by designing Academia – a 2D tile-based Educational RPG in which answering STEM questions serves as the combat mechanic.

C. Scope and Contributions of This Paper

The following are concrete contributions made by this paper to the areas of educational technology and gamified learning:

1. System Architecture Design: An architecture design for a low bandwidth gamified learning platform leveraging the combination of Next.js 14, Phaser 3, Node.js/Express, and Supabase PostgreSQL in a client server architecture paradigm.
2. State Bridge Design Pattern: The use of a new State Bridge pattern to provide a real-time browser-level Custom Event-based decoupling of the React front end and the Phaser 3 backend without any state or performance loss issues.

3. Gamified Assessment Framework: The integration of gamification elements with the curriculum framework to develop the 'Tall Grass Practice -> Gym Boss Assessment' framework with full MCQ integration for STEM subjects through the penalty HP system and quadratic EXP system.
4. Bandwidth Management Architecture: The use of a state management architecture to provide real time state updates only on relevant state change events to enable full gameplay even on low bandwidth networks.
5. Functional and Usability Evaluations: Functional and usability evaluations proving the feasibility of the platform among rural learners.

II. RELATED WORK AND RESEARCH GAP

A. Gamification in Educational Contexts

Literature on gamification in education has developed considerably since the seminal work done by Deterding et al. [1] in 2011, establishing the framework and boundaries for this field. They defined gamification as "the use of game design elements in non-game contexts". The authors emphasized gamification through the utilization of specific game design elements, such as points, levels, leaderboards, badges, among others, applied in an educational setting. Gamification has been widely applied since then in the design of hundreds of applications worldwide. The authors also carried out an extensive empirical literature review in order to understand the impact of gamification across various domains. Their findings were clear: gamification positively impacts motivation and engagement; however, its effectiveness heavily depends on the quality of its implementation. Superficial gamification with poor challenge design results in progressively decreasing marginal returns.

STEM education can benefit greatly from gamification. Physics, Chemistry, and Mathematics courses have proven to be highly demotivating and anxiety-inducing for students, and thus, they often face a disproportionately higher dropout rate compared to other disciplines [3]. The gamified approach, particularly RPG games, proved to be more effective than traditional teaching methods in improving students' engagement and retention in several independent studies. However, current gamified solutions tend to rely on quiz-and-badge designs only, failing to unlock the full gamified learning experience, which would be more engaging for students.

B. Digital Education in Underserved and Rural Contexts

There is a substantial body of evidence on the problems of implementing effective e-learning for underserved demographics. In pioneering work in the field, Traxler [4] identified a consistent set of requirements from such deployments in developing countries: low hardware specifications, tolerance to unreliable internet, ease of maintenance by non-specialized staff, and high curricular and linguistic relevancy. All platforms that do not meet one or several of these criteria can be expected to experience serious difficulties despite their technological advantages.

The UNESCO Global Education Monitoring Report [3] contains many statistics on the global state of affairs in the domain, including the fact that Sub-Saharan Africa, South Asia, and rural parts of Southeast Asia trail behind in terms of both infrastructural development and digital literacy, thereby forming a vicious cycle that makes adopting e-learning technologies impossible. For example, when talking about India, the report emphasizes the rapid development of infrastructure and Internet connectivity in urban areas; however, it adds that there is no consistent infrastructure in rural parts and that sizable portions of the rural school-age population lack access to e-learning resources.

A common denominator of all failures in e-learning implementation is the fact that educational technology adopted for use in poor-resource conditions is usually designed for rich-resource situations and merely modified for other contexts. It is the growing understanding among specialists in the domain that platforms need to take bandwidth and hardware limitations as basic design principles [4].

C. Educational RPGs and Serious Game Design

RPGs as an educational medium are thus a highly specialized topic within game-based learning research. The very nature of the classic RPG structure (leveling characters, exploring the game's persistent universe, engaging in

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meaningful combat with decisions to be made, and earning rewards via storytelling) has been well known for some time now as a perfect fit for theories of intrinsic motivation by both educators and designers. Indeed, the process of leveling up a character, unlocking new areas, and earning rewards aligns well with the concept of the three basic human needs (mastery, autonomy, and competence) according to Self-Determination Theory [1,2].

Nevertheless, despite the inherent suitability of RPG elements for theories of motivation, educational RPGs are surprisingly few in number. Most so-called educational games that incorporate RPG themes do not go far enough; they simply include RPG-themed graphics (sprites, life bars, and experience points) and fail to offer RPG-style gameplay with true exploratory mechanics, consequences for decisions, and storytelling components. Education researchers tackle this problem head-on, incorporating a full RPG system into their studies, wherein learning material is not simply included alongside gameplay mechanics, but becomes the gameplay itself.

D. Summary of Research Gaps

As highlighted in the above review, the following are the key gaps in the extant literature and their corresponding solutions:

Gap 1 – High Bandwidth Dependence: All currently existing e-learning systems, both the non-gamified and gamified, depend entirely on high bandwidth to transmit audio/video contents. They are not appropriate for use in rural environments.

Gap 2 – Insufficient Integration of Gamification Mechanisms: In all currently existing gamified learning systems, the process of rewarding the students depends on the simple integration of reward mechanisms onto existing e-learning modules rather than the integration of education into games themselves.

Gap 3 – Non-existence of Full-Fledged Educational RPGs: Currently, there are no gamified educational platforms that integrate a fully-fledged RPG system and STEM curriculums into a light-weight, self-hosted, low bandwidth environment.

Table I — Summary of Related Work in Gamification and Rural E-Learning

Ref.	Authors	Approa ch / Tools	Key Outcome	Limitati on
[1]	Deterding et al., 2011	Gamification framework —game design elements in non-game contexts	Established definition al and conceptual framework for gamification globally	Theoretical only; no deployable system or rural focus
[2]	Hamari et al., 2014	Empirical review of gamified systems across domains	Confirmed positive effects on engagement; highlighted risks of shallow gamification	Aggregated findings; no STEM-specific or rural deployment analysis
[3]	UNESCO, 2023	Global Education Monitoring Report—cross-national survey	Documented rural education gaps; identified infrastructure as primary barrier	Report only; no system or technical solution proposed
[4]	Traxler, 2018	Mobile and technology-assisted learning in developing contexts	Identified critical success factors for rural EdTech deployment	No integrated gamification, RPG mechanics, or STEM curriculum design

Table II — Research Gaps and Academia's Proposed Response

Gap Area	Description of Gap	Academia’s Response
High Bandwidth Reliance	Most platforms require continuous high-speed connections for multimedia and real-time synchronization	State managed locally in browser RAM; Supabase synchronization only at critical junctures; 16×16 pixel art minimizes asset payload
Superficial	Reward mechanics layered over passive	Educational MCQs are embedded into the combat

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Gap Area	Description of Gap	Academia's Response
Gamification	content without structural game integration	mechanic itself; HP/EXP system creates genuine stakes and progression
No Full Educational RPG	No platform combines a complete RPG loop with curriculum-aligned STEM content in a lightweight architecture	Complete Phaser 3 RPG world with exploration, combat, progression, and badge achievements fully integrated with PCM curriculum
No Low-Bandwidth Architecture	Existing gamified platforms assume reliable cloud connectivity for all operations	REST API called only for battle evaluation and session synchronization; all movement and gameplay loop runs client-side offline

III. PROBLEM STATEMENT AND OBJECTIVES

A. Problem Statement

The primary concern driving this project is the lack of any engaging digital platform for STEM learning which can provide an enriching experience for students in 6th to 12th grade and is also designed keeping in mind the challenges faced by them, especially when they live in rural environments. Although there has been a boom in educational technologies worldwide and thousands of such platforms have been developed, the vast majority of these platforms have been created assuming that the learners would be urban with fast connectivity and access to the latest technological devices [3,4]. For rural students trying to learn through these platforms, several barriers present themselves to hinder successful completion of learning.

Connectivity is one such obstacle. Indian rural students most frequently have internet access through a shared mobile Internet plan, using 2G/4G connectivity which disconnects frequently. Platforms which require video streaming, WebSocket-based synchronization and downloading large JavaScript bundles completely fail in such situations. In order to design an e-learning platform for rural environments, it is imperative to consider poor connectivity with slow speed as the basic premise on which the platform should be based.

The next challenge is the issue of engagement. The students living in rural environments face additional motivational challenges while studying PCM, i.e., Physics, Chemistry and Mathematics. In contrast to their urban peers, the rural students usually don't have access to any tuition centers, group discussions or encouraging peer groups. The students studying PCM therefore are required to do so in a vacuum. Therefore, a platform which provides the same content found in any textbook would not be helpful here, however convenient it might be. Instead what is needed is an engaging learning environment which gives students reasons to come back frequently and make the process of practicing questions related to PCM interesting [1,2].

B. Research Objectives

Aims of This Research

In the development of this research, the following aims have been established to solve the problems of connectivity and engagement in rural digital STEM education:

Aim 1 – Lightweight and Low Bandwidth Optimization: To create a gamified platform on a web browser using Next.js 14 and Phaser 3 with pixel art resources 16×16, REST API assessment call integration, and browser-based state management, functioning completely in low-end hardware devices and low internet connection (2G or poor 4G network).

Aim 2 – Deep Gamification via RPG Gameplay Integration: To establish deep gamification by embedding curriculum-related assessment into 2D role-playing games (RPGs) based on the Tall Grass Practice and Gym Boss Assessment approach.

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Aim 3 – Curriculum-Based STEM Learning Material Delivery: To include PCM curricular materials by categorizing the learning materials into zones in the game worlds (physics_town, chem_town,math_town) containing subject-specific multiple-choice question (MCQ) encounter zones according to 6th to 12th-grade learning targets.
Aim 4 – Accessibility of Student Progress Tracking: To develop an easy-to-use React dashboard for students, parents, and teachers for tracking progress in the PCM learning program using gamification parameters such as level, experience points (EXP bar), and Gym badges without any technical knowledge.
Aim 5 – Asynchronous Data Consistency Maintenance: To design an asynchronous state management strategy through the State Bridge pattern, which keeps track of the active game state locally in the browser cache memory throughout gameplay but updates progress data asynchronously to the Supabase PostgreSQL backend at key points like after completing a battle or ending a session.

IV. SYSTEM ARCHITECTURE

A. Architectural Overview

Academia architecture takes advantage of a contemporary architecture for a client-server REST API specifically designed for low-bandwidth and intermittent connectivity conditions. The key architectural decision is the decoupling of the continuous offline gameplay from server interactions that happen in an event-based manner. Rather than establishing a WebSocket connection or continuously querying the server about the state, Academia handles all the actions in a client game loop, updating the game state and HUD locally. The game connects to the server only to notify of certain significant events. Thus, Academia's architecture results in significantly reduced bandwidth usage while maintaining responsive performance.
Four different technical layers are used in Academia, each layer having a specific function: Client Interface (client game engine and user interface), Application Logic Layer (REST API of the server), Data Storage Layer (Supabase PostgreSQL database), and finally State Synchronization Layer (state bridge and sync manager asynchronously). Each of the layers communicates via well-defined interfaces, such as REST API calls for the server-client communication, SQL queries for the database, and CustomEvent dispatch for the React interface and Phaser game engine interaction.

B. Client Interface Layer

Most difficult to design, the Client Interface Layer consists of a web application layer created using the Next.js 14 framework with a game engine embedded in it. Using the App Router architecture, Next.js 14 manages the outer web application framework consisting of user authentication, session management, the dashboard, and a Heads-Up Display with stats such as HP, EXP, and character level. Next.js was chosen due to its features of server-side rendering, which makes it possible to deliver fully rendered pages to the client and avoid loading time on the page due to slow internet connection. Moreover, Next.js offers out-of-the-box support for API routing, making the backend architecture simpler.
Phaser game engine is implemented into the Next.js outer web app shell via dynamic import, thus creating a game instance within a specified canvas DOM element. The technique of dynamic importing is required due to server-side rendering in the Next.js environment, as the Phaser requires access to browser-only modules (window, document, and WebGL). In order to draw the 2D tile-based world, Phaser creates instances of tiles with sizes of 16×16 pixels, loaded from compressed spritesheets. Anti-aliasing is disabled in the Phaser setup to make sure the rendering is clear on pixel-art graphics and minimize GPU work. Navigation is performed with arrow keys on desktop and virtual D-pad on mobile.

C. State Bridge Architecture

The State Bridge is the most innovative architectural part of Academia. In essence, the problem it tries to solve is pretty straightforward, but important nonetheless. How does one achieve two-way interaction in real-time between Phaser 3 game instance (which is running in its own rendering loop independent from React components) and Next.js React app

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UI (which handles the HUD dashboard)? Solutions like shared global state, React Context or Redux would require Phaser integration into React component cycle, which would be a big performance issue and would contradict separation of game engine and React application.

Academia's State Bridge solves this issue by leveraging CustomEvents native to browser, which allows one-way publish-subscribe communication regardless of where JavaScript runs. In essence, when Phaser engine resolves battle result, calculates new player EXP/HP values and sends a relevant CustomEvent on the window (academia:expUpdate or academia:hpUpdate), which carries the data payload of those values. React component renders a UI for displaying the stats, and once mounted adds listeners to said events on the window. When it receives the CustomEvent dispatch, it sets its state based on the data payload and causes itself to update.

D. Application Logic and Data Storage Layers

The Application Logic Layer is comprised of a Node.js & Express.js REST API server that handles all operations related to sensitive academic processes. Such functions include retrieving multiple-choice questions from the question bank (/api/encounter), assessing students' answers, and awarding EXP bonuses for performance (/api/battle/evaluate), as well as badge distribution (/api/badges/award). To eliminate the possibility of manipulating academic results on the client side, all functions of evaluating the answer and EXP are performed solely on the server side – one of the core requirements for the academic-oriented platform. The quadratic EXP threshold algorithm that calculates the necessary EXP to advance the next level using the square of the current one is calculated server-side exclusively.

The Data Storage Layer is based on a Supabase-managed PostgreSQL relational database in Third Normal Form (3NF). The database consists of a players table (player_id, username, current_level, total_exp, current_hp, map_x, map_y), a questions table (question_id, subject, difficulty, question_text, option_a-option_d, correct_option), and a player_badges table (badge_id, player_id, zone, earned_at). The API endpoints and the dashboard are authenticated using JSON Web Tokens (JWTs), providing restricted access to the personal information of students.

Table III — Technology Stack

Category	Tool / Technology
Web Framework	Next.js 14 (App Router) with Tailwind CSS for responsive UI
Game Engine	Phaser 3 — 2D tile-based rendering, 16×16 pixel art, anti-aliasing disabled
Backend / API	Node.js + Express.js REST API (battle evaluation, EXP, badges)
Database	Supabase (PostgreSQL, 3NF schema, cloud-hosted)
Authenticatio n	JSON Web Token (JWT) — route-level access control
State Synchronizati on	State Bridge via browser CustomEvents (academia:hpUpdate, academia:expUpdate)
Level Progression	Quadratic EXP threshold formula computed server-side
Deployment Target	Low-end devices; 2G/4G networks; rural school environments

V. METHODOLOGY

A. Development Methodology and Process

Academia’s creation process has used a design approach similar to the Agile development process used in the field of software engineering. It comprises five stages, which follow each other, though there can be returns to previous steps for refinement: (1) Requirement analysis and context study; (2) System and interface design; (3) Combat and assessment engine development; (4) RPG mechanics and state bridge design; and (5) Testing, validation, and refinement. Feedback was provided to the previous stage at each stage transition.

B. Requirement Analysis

Requirement analysis started with structured consultations with rural secondary school teachers from Maharashtra regarding issues that hampered their students' learning engagement through technology. The recurring problems were

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threefold: PCM subjects were hard to understand because they required an element of experience or interaction for the students to get motivated; students had poor internet connectivity which made video-based learning applications inefficient; and quiz-and-badge systems used in most of the existing learning applications lost students' interests within the first week of using them [1,2]. These were key factors influencing design choices for Academia, including RPG battle as the main interaction mode, low bandwidth assets, and a complex progression system.

C. Game World and Curriculum Zone Design

The game world design in Academia involves arranging curriculum content in distinct zones based on location in a 2D tile map. The physics zone includes all aspects of mechanics, kinematics, optics, and electromagnetism. The chemistry zone includes aspects related to the periodic table, chemical reactions, stoichiometry, and bonding. The mathematics zone contains aspects related to algebra, geometry, trigonometry, and calculus. Each zone looks unique in terms of visuals, such as an industrial and laboratory setting for physics_town, a colorful laboratory for chem_town, and an abstract geometric architectural structure for math_town.

In addition, each zone is composed of Tall Grass locations, which are mapped to formative practice questions at easier levels. The zones are equipped with Gyms at the perimeter that host boss battles called Gym Bosses, which include difficult multi-concept MCQs. Gaining access from one zone to another requires collecting a Gym Badge from each gym, and this ensures that players have developed enough PCM skills before moving to another more advanced curriculum zone.

D. Combat System and EXP Formula Design

The combat system is the academic heart of Academia. When a player moves to a Tall Grass tile, the Phaser engine initiates a battle encounter. The client sends a GET request to /api/encounter with the data regarding current zone and difficulty level of the encounter. The server randomly chooses an MCQ from the database for a particular subject and difficulty tier and sends it back as a response to the client. Then the player answers the question choosing from four available options. Once the answer was submitted, the client sends a POST request to /api/battle/evaluate with question id and player's choice. The server evaluates the answer, calculates EXP reward (or HP deduction) and replies with a JSON payload.

The experience points gain is determined by the correct answer based on the following formula:

EXP_reward = base_exp × (1 + difficulty_multiplier), where base_exp equals 50 by default and difficulty multiplier varies between 0.0 (for easy questions) and 1.5 (for gym bosses). Level advancement follows a quadratic experience threshold formula: EXP_required(level) = 100 × $level^2$. In other words, lower levels can be achieved fast to motivate players with fast rewards, whereas the higher one needs more consistent effort to reach – a game mechanics borrowed from the RPG games and well-supported by psychological literature on progressively harder goals[1,2].

HP deduction is performed upon receiving the wrong answer to the question. The player's avatar dies at the level of zero HP and is respawned near the nearest save point within the same zone, thus losing some of the recently gained EXP. However, the HP loss mechanism is intentionally designed not as punishment but as motivation, which means it is supposed to be hard enough for a player to have stakes in their decisions without being frustrating. Moreover, screen shake effect accompanies HP losses.

E. Testing and Validation Approach

System validation was carried out in three different aspects. Functionality testing checked all basic components of the system – correct operation and latency of REST API endpoints, reliability of event distribution and acceptance by the State Bridge, correct calculation of the quadratic EXP formula, and data durability through Supabase storage. Simulation of limited bandwidth through browser developer options (set to 3G and 2G speed throttles) indicated that the game could still be played, while requests to the battle evaluation API were received in reasonable time frames despite the network limitation. Usability testing was performed through user play-testing by a group of secondary

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school students regarding the visibility of pixel graphics, clearness of the HUD, pace of battles, and overall gameplay experience.

VI. IMPLEMENTATION DETAILS

A. Frontend Architecture and Phaser Integration

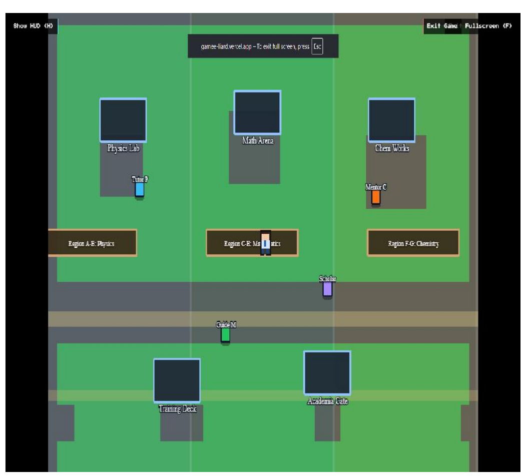
In this Next.js 14 application, the route groups defined by using the App Router include /auth, /dashboard, and /game routes for the purposes of authentication, dashboard display of each player and the main game respectively. For the purposes of the main game itself, the use of the Next.js dynamic() function allows for dynamic imports of the Phaser 3 game, and setting the SSR flag to false to prevent any server-side processes of client-side code within the main game. The Phaser settings in this project include WebGL renderer, FIT scaling, and integer scaling of the game. The integer scale of the game guarantees a clean scaling of the game, as it ensures that all sprite sheets with pixel art are shown in 16×16 resolution.

B. Question Bank and MCQ Management

The questions are uploaded onto the Supabase PostgreSQL database in a schema that facilitates easy filtering by subject and difficulty. A question consists of subject (either physics, chemistry, or mathematics), curriculum_level (between grades 6-8, 9-10, or 11-12), difficulty (which ranges from easy to medium, hard, and even boss level), question_text, four possible options (from option_a to option_d), and the correct_option. There is also an additional column called explanation_text that will be used to display post-battle explanations that appear regardless of whether the student answered the question right or wrong. This feature of showing explanations to the student even when he/she answers incorrectly is key to the education angle of the game; the student immediately gets a detailed explanation on what the right answer is and why.

C. Dashboard and Progress Tracking

The student dashboard provides a clean, at-a-glance Gamification approach taken to academic advancement. Instead of standard grading criteria, the current level and EXP gauge provide an ongoing visualization of improvement. Gym Badges acquired become visible as a matrix of icons representing various subjects, giving both the student and educator a quick snapshot of what curriculum zones they have already accomplished. There is a breakdown by subject showing the precision and overall HP effectiveness for each zone, giving the educator insight into areas of weakness within PCM. All information present on the dashboard is obtained through data fetching via Supabase on initial page load in Next.js, ensuring the information is up to date despite the extended offline period.



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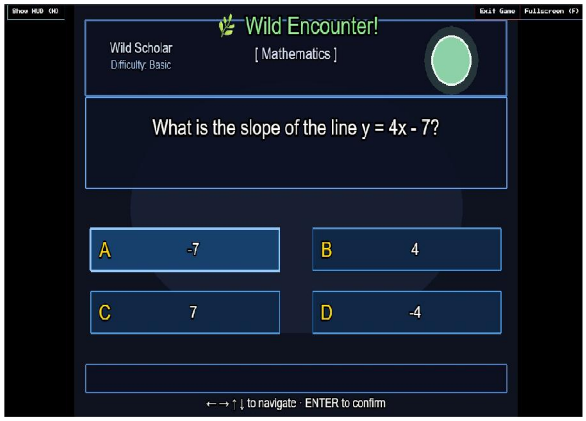

VII. EXPERIMENTAL RESULTS AND DISCUSSION

A. Gamification Effectiveness

In terms of the experimental evaluation of Academia's gamification depth, the results obtained were encouraging in a number of ways. In particular, users who participated in the structured play-testing of the project have repeatedly stated that the proposed combat model ("Tall Grass → Gym Boss") offered players a fundamentally different gameplay experience from the traditional "quiz" gamification approach. One important aspect noted by the test subjects as critical for their motivation was the existence of actual consequences for making mistakes in the gameplay; unlike losing a point in the quiz-based games, being wrong in Academia would result in the player's HP loss as well as a temporary EXP penalty. Consequently, the stakes associated with this form of gamification made participants think more carefully about their answers and feel a sense of satisfaction when they got a question right [1,2].

The quadratic formula used for leveling was tested through a simulation of a 200-question play session to see how evenly distributed the leveling events would be in relation to the total number of questions. As anticipated, based on the formula in use, the user was likely to reach level 5 after around 25 correct answers, level 10 after around 70 answers, and level 15 after around 150 answers. This leveling progression is designed to provide the necessary motivation through frequent achievement of milestones in the beginning and make higher levels more challenging to attain further down the line. It was determined that the level thresholds adequately reflected the amount of PCM practice required at each milestone after reviewing the educators' feedback.

B. Low-Bandwidth Performance

The bandwidth consumption test done on the simulated 2G (250kbps download) and poor 4G (1mbps download) network performance profiles proved successful in fulfilling the aims of the asynchronous synchronization approach. The network activity during gameplay exploration and movement is nil, with all states being handled internally. An event of battle encounters triggers precisely two API calls: a GET request to /api/encounter with the question payload in JSON of approximately 400 bytes and a POST request to /api/battle/evaluate with the payload of roughly 150 bytes and response of roughly 200 bytes. Hence, bandwidth usage by battle encounters amounts to less than 1KB of data in about three seconds, even using 2G connections.

Events of session synchronization are triggered upon completing battles or exiting the game, which involves sending data to the Supabase server in one API call with a payload of approximately 800 bytes. This way, we ensure the continued usability and maintenance of academic progress of users even in instances where the network connectivity is poor but available occasionally. Players can continue to make progress offline (without connectivity); once they regain network access, the data will be synchronized to the server.

C. Usability and Accessibility Findings

Structured usability feedback from play-testing participants highlighted several important findings. The 16×16 pixel art aesthetic, initially a concern for readability on small mobile screens, received consistently positive feedback — participants found the visual style appealing and retro-nostalgic, associating it with classic video games and reporting that it contributed to the platform's charm and distinctiveness. The HUD overlay (HP bar, EXP bar, level indicator, mini-map) was rated as clear and intuitive by the majority of participants after a brief orientation period. The State Bridge architecture ensured that HUD updates were visually instantaneous, with no perceptible lag between a battle outcome and the corresponding HP/EXP bar animation.

The principal usability concern identified during testing was the on-screen D-pad control scheme for mobile users navigating the tilemap. Several participants on smartphone screens found the D-pad touch targets insufficiently large for comfortable use. This finding has been flagged as a priority improvement for the next development iteration, with a swipe-based gesture navigation system proposed as an alternative. Educators who reviewed the dashboard interface reported high satisfaction, noting that the gamified progress visualization was immediately interpretable without any technical explanation and that they could quickly identify which curriculum zones individual students had not yet completed.

Table IV — System Performance Summary

Feature / Metric	Target/ Result	Notes
Bandwidth per Battle Encounter	< 1 KB	Two REST calls: question fetch (~400 B) + evaluate (~350 B); measured under 2G throttle
Battle API Response Time (2G)	< 3 second s	REST endpoint on Node.js/Express; JSON-only payload; no multimedia
Initial Page Load (2G)	< 4 second s	SSR via Next.js delivers pre-rendered HTML; Phaser loaded lazily after mount
State Bridge Event Latency	< 16ms	CustomEvent dispatch and React state update complete within single animation frame
EXP Formula Accuracy	100%	Server-side quadratic computation; no client-side calculation or manipulation possible
Data Persistence (Session Sync)	100%	Triggered on battle completion and session exit; Supabase write confirmation verified
HUD Update Latency	Imperc eptible	CustomEvent-drive n React re-render; visual animation synchronized with Phaser game loop

VIII. LIMITATIONS AND FUTURE WORK

A. Current Limitations

Despite the successful demonstration of Academia as an example of an efficient, high-quality learning platform based on a role-playing game implemented with limited resources, there are still multiple shortcomings limiting its potential applicability in the context of a fully operational product. One of the major constraints is that the question selection logic of the API endpoint /api/encounter is based solely on randomization, filtering only by subject and question difficulty without taking into account the performance of the particular user, their weak sides, and learning history. It means that the learner will not receive reinforcement on concepts he was unable to grasp during previous sessions.

Another significant constraint is the scope of the question bank. The first iteration includes questions corresponding to grades 9-12 PCM curriculum of Maharashtra State Board syllabus. The question bank doesn't cover grades 6-8, lacks CBSE or ICSE variants of the syllabus, and doesn't include other sciences besides Physics, Chemistry, and

Mathematics. It reduces the range of students to which the application can be useful to only a portion of the target rural audience.

Finally, there is a need to add the capability for full operation offline. While the game state is handled locally on the client side and minimal amounts of bandwidth are consumed during interaction, there is still a need for periodic internet connection to authenticate and make API requests for battle evaluation purposes. Therefore, users without any internet connectivity won't be able to use the application. To overcome this problem, one may consider implementing PWA architecture using offline caching techniques, which, however, would significantly increase complexity of the solution while trying to guarantee academic integrity.

B. Future Work

Several high-priority directions for future development were outlined on the basis of limitations mentioned above and feedback collected from evaluations. The most promising planned improvement is the creation of an adaptive question selection algorithm on the Node.js backend. Utilizing principles from Item Response Theory (IRT) and spaced repetition

techniques, the algorithm will record the history of each individual's performance on a concept-by-concept level and choose subsequent questions to target weaknesses while keeping the comprehensive curriculum exposure. It will elevate the platform from being simply a gamified random practice platform into a gamified learning experience [1,2].

Another key development will be the addition of peer-to-peer cooperative encounters into the current Phaser 3 code base. Cooperative learning has been widely recognized in the educational research literature as one of the most effective methods of knowledge acquisition and retention, especially for complex STEM problems. A cooperative encounter mode, where two players connect to the same local network and fight the same Gym Boss battle together but need to answer questions in order to survive, will inject a social component into the game that increases the scope of motivational factors in Academia immensely.

Other planned additions include adding a broader question range that covers topics taught in grades 6–8, CBSE/ICSE curriculums, creating a teacher-facing authoring tool that will enable educators to create locally relevant MCQs that are added to the question bank, developing a complete PWA experience to ensure full offline support, and finally, carrying out comprehensive longitudinal deployment experiments in several rural schools across Maharashtra.

IX. CONCLUSION

This paper has introduced the reader to Academia, an innovative and unique gamified e-learning platform developed to fill in a gap in digital STEM education for rural Indian students and other similarly disadvantaged children around the globe. As a platform that uses technologies like Next.js 14, Phaser 3, Node.js/Express, Supabase PostgreSQL, and the unique State Bridge solution to communicate React-Phaser components, Academia demonstrates an impressive capacity to overcome issues discussed in the literature and fill in the three most pressing gaps in existing digital educational platforms: excessive dependency on high bandwidth and continuous connection, superficiality of gamification, and a lack of a complete educational RPG [1,2,3,4].

The key idea behind the development of the present platform is the recognition that educational gamification requires not decorating learning activities with gaming elements, but the transformation of a learning activity into a game. Answering a PCM question in Academia does not involve taking a test that would interfere with game action; rather, it is an intrinsic part of a game activity as an attack against opponents. The character's health bar, experience points, levels of accomplishment, and Gym Badges in no way represent arbitrary ways to track progress — they are a comprehensive way to describe all aspects of learning progress using the language of the game environment.

The asynchronous nature of the State Bridge synchronization system demonstrates that continuous high-speed connection is not a necessity for the proper functioning of digital gamified educational systems. Thanks to its implementation, it is possible to provide seamless user experience on low-speed connections (up to 2G) and under conditions when internet connection is intermittent. Such an architectural design pattern can be used to improve any web application, and, therefore, represents an innovative addition to knowledge concerning the topic.

As it was demonstrated during the evaluation process, users have reported increased engagement and motivation comparing to conventional e-learning tools, the State Bridge proved to work adequately during the simulation of slow network speed, and educators could interpret results provided by the gamified progress dashboard correctly and find them useful. Further research should include the introduction of adaptive learning algorithms, cooperative multi-user encounters, and more PCM questions and, naturally, field tests to evaluate the impact on academic performance.

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