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Dynamic QR Code Based Intelligent Attendance System Architecture and Real-Time Gamification for Academic Digital Transformation

Brigitta Callula[1], Untung Rahardja[2], Nur Azizah[3], Ihsan Nuril Hikam[4*]
[1]Eduaward Institute, United Kingdom
[2,3,4]Faculty of Science and Technology, Universitas Raharja, Indonesia
[1]brigitta_call@eduaward.co.uk, [2]untung@raharja.info, [3]nur.azizah@raharja.info, [4]ihsan.nuril@raharja.info
***Corresponding Author**

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ABSTRACT

Digital transformation in higher education institutions necessitates efficient and secure academic administration governance. Conventional attendance systems and static QR codes have proven vulnerable to attendance manipulation (buddy-punching). Furthermore, the absence of duration tracking instruments makes the attendance routine lack psychological stimulation for student engagement. **This study aims** to design, implement, and evaluate a Smart Attendance System architecture that integrates Dynamic QR Code authentication with real-time gamification engine computation. **This research employs** the Design Science Research Methodology (DSRM) integrated with the Agile Scrum cycle. The Client-Server architecture is built using the Time-based One-Time Password (TOTP) algorithm for QR Code regeneration every 10 seconds and formulates the timestamp difference (check-in/check-out) into reward point computations. Black-Box testing validates that the system absolutely blocks the anomalies of expired codes and ID duplications. **The throughput metric evaluation** proves a massive acceleration in operational time, reducing the class attendance duration ($n = 40$) from an average of 345 seconds to 42 seconds, resulting in an efficiency of 87.8%. This system architecture is proven to definitively mitigate administrative security loopholes and significantly reduce time inefficiency, while simultaneously exploiting duration tracking into reward metrics to engineer discipline within the digital academic ecosystem.

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1. INTRODUCTION

Digital transformation in higher education institutions is no longer merely an adaptation option but a fundamental urgency to create efficient, transparent, and automated academic ecosystem governance. One of the most crucial administrative pillars in lecture operations is attendance management. Historically, mechanically operated attendance recording whether through manual paper sign-ins or static web portal entries has proven to trigger massive inefficiencies in lecture time allocation [1]. Furthermore, the transition toward early-generation digital systems has not fully provided a comprehensive resolution, given the high systemic vulnerability to academic database integrity due to authentication security loopholes [2].

The most essential problem with conventional attendance systems and Static QR Codes is their inability to mitigate attendance anomalies, specifically data manipulation practices or buddy-punching. In a static QR architecture, students can easily share screenshots with peers who are not physically present in the classroom [3, 4]. Besides degrading the validity of academic reporting data, this attendance verification process is often slow and not synchronized in real-time, resulting in repetitive administrative workloads for both lecturers and academic staff.

On the other hand, a fundamental flaw of current digital attendance instruments is the paradigm that strictly focuses on binary recording (present or absent), without measuring the students' actual participation duration. Legacy systems fail to facilitate precise check-in and check-out timestamping, leaving no metric to measure the quality of time discipline [5]. This condition is exacerbated by monotonous system interfaces, turning the attendance routine into a mere administrative obligation without any psychological stimulation to enhance student engagement and motivation in maintaining academic discipline [6, 7].

Addressing these architectural and behavioral gaps, this study proposes the development of a Smart Attendance System that integrates a high-level authentication security layer with a behavior-based motivational engine [8]. This solution is engineered by combining Dynamic QR Codes where the code automatically regenerates within a short Time-to-Live (TTL) interval to block data interception with a real-time gamification engine [9, 10]. Through this integration, timestamps from the check-in to check-out processes are not only secured in the database but also dynamically computed by the server algorithm to be converted into reward points, leaderboards, and interactive activity notifications [11, 12].

Based on the aforementioned problem foundation, this research is specifically directed to actualize three main objectives, namely:

- Designing and implementing a Client-Server-based Smart Attendance System architecture that combines Dynamic QR Code security protocols and gamification computational logic.
- Validating the functional reliability and security of the system in mitigating attendance authentication manipulation (buddy-punching).
- Evaluating the system's performance metrics quantitatively by comparing the efficiency of data transaction processing time (throughput) against conventional attendance methods.

Through these objectives, this study contributes an integrated Smart Attendance System architecture that extends attendance management beyond conventional presence verification. The proposed approach combines secure Dynamic QR Code authentication, participation duration tracking, and real-time gamification within a unified Client-Server environment. Unlike conventional attendance systems that primarily focus on recording presence, the proposed architecture utilizes check-in and check-out timestamps as measurable participation data that are subsequently transformed into reward points and leaderboard metrics. This integration provides a technical foundation for improving authentication security, operational efficiency, and data-driven student engagement within the higher education digital ecosystem.

2. LITERATURE REVIEW

2.1. Evolution of Attendance Authentication Security Protocols

Digital transformation in academic governance has driven the transition of attendance recording methods from mechanical logging to biometric authentication systems and smart networks based on the Internet of Things (IoT) [13–15]. Although basic technologies such as static Quick Response (QR) Codes are widely adopted due to their cost efficiency, previous literature confirms that static architectures possess a fatal systemic vulnerability to visual duplication. This facilitates authentication manipulation loopholes, such as buddy-punching practices through screenshot mediums [16].

To mitigate these anomalies, attendance security architectures continue to evolve. Various recent studies have begun implementing layered protection, such as the use of time-based Animated QR Codes, up to the combination of optical scanning with facial recognition biometric verification as secondary authentication [17, 18]. Furthermore, infrastructure-level analysis has also been conducted to secure attendance data payloads using cryptographic protocols in IoT network architectures. The implementation of Dynamic QR Codes adopting the Time-based One-Time Password (TOTP) mechanism is proven to effectively ensure that authentication

is only valid if performed in real-time at the code projection location, while radically reducing data transaction processing time (throughput) [19, 20].

2.2. Gamification Architecture in Integrated Software Environments

Although updates to security protocols have successfully suppressed data manipulation rates, User Experience (UX) evaluations of various attendance systems indicate that administrative digitalization has not been fully capable of stimulating users' intrinsic motivation [21]. Gamification in software engineering is not merely the addition of interactive visual elements but the integration of computational logic on the backend to engineer user engagement based on academic behavioral metrics [22, 23].

Unlike legacy attendance systems that process data in a binary manner (present/absent), real-time gamification computational architecture requires sequential data processing. The system tracks the initial (check-in) and final (check-out) timestamps of each student entity. The difference in participation duration is then computed using the basic mathematical formula $\Delta t = t_{out} - t_{in}$. This Δt value is subsequently processed through a data pipeline to be converted into reward units (points) that instantly synchronize with the leaderboard database and trigger aggregated activity notifications. This architectural manipulation is empirically proven to improve user discipline and retention through operant conditioning mechanisms [24, 25].

2.3. State-of-the-Art and Research Gap

To validate the originality and significance of the proposed architectural development, a comparative synthesis was conducted against four recent primary studies publishing Smart Attendance System innovations [26]. The State-of-the-Art matrix in Table 1 illustrates the functional limitations of system architectures in previous studies.

Table 1. State-of-the-Art Matrix and System Functionality Comparison

Primary Journal Reference	Main Authentication Method	Buddy-Punching Mitigation (Security)	Duration Tracking (Check-in / Check-out)	Gamification Engine & Real-Time Reward
[27]	Animated QR Code	Yes (Time-based Animated Pattern)	None	None
[28]	QR Code & Facial Recognition	Yes (Secondary Biometric Verification)	None	None
[29]	QR Code on IoT Network	Yes (IoT Architecture Cryptographic Validation)	None	None
[30]	Standard QR Code	None / Limited	None	None

Based on the recent literature review in Table 1, it is evident that the trend of Smart Attendance System development is highly concentrated in two main domains: network/authentication security extensification and interface evaluation (User Experience). Previous research has successfully designed anti-data manipulation architectures via animated QR codes, IoT network validations, and facial biometric integration. However, regardless of how advanced these systems are in securing data validity, all the aforementioned literatures still inherit the weakness of legacy architectures: the absence of user participation duration tracking (check-in to check-out).

Current systems merely operate as "presence" recording instruments, without any integration into a rewarding system. This research is specifically presented to fill this innovation gap. The proposed architectural design not only ensures authentic authentication security through Dynamic QR Codes but also exploits timestamp metrics to drive a gamification engine that functions to stimulate student engagement through points, leaderboards, and real-time analytical insights [31, 32].

3. METHODOLOGY

This research adopts the Design Science Research Methodology (DSRM) as the primary framework [33, 34]. The selection of DSRM is based on the research characteristics that focus on designing, developing,

and evaluating an IT artifact to solve a specific organizational problem, namely administrative inefficiency and the vulnerability of academic attendance security. This methodology ensures that the developed system possesses a strong theoretical foundation as well as measurable pragmatic value [35].

3.1. Stages of Design Science Research Methodology (DSRM)

The execution of this research is mapped into six sequential DSRM stages modified according to the development needs of the Smart Attendance System, which are:

- Problem Identification and Motivation: Exploring the vulnerabilities of static attendance architectures (buddy-punching practices) and the absence of lecture duration tracking instruments that impact low student discipline and engagement [36].
- Definition of Solution Objectives: Establishing the artifact's success parameters, which include: the server's capability to regenerate Dynamic QR Codes within seconds, and the gamification engine's capability to convert check-in and check-out durations into timestamps and reward points in real-time.
- Design and Development (Agile Integrated): The software engineering phase where the Client-Server architecture, network topology, database design (Entity Relationship Diagram), and user interface logic (UI/UX) are built using an iterative cycle. (This phase is specifically elaborated in sub-section 3.2).
- Demonstration: Deploying the system prototype into a staging server environment and demonstrating its operational capabilities through controlled lecture simulations (pilot project).
- Evaluation: Empirically measuring architectural resilience and algorithm efficiency. The evaluation focuses on functional load testing and processing time acceleration (throughput).
- Communication: Documenting the architectural design, algorithms, and evaluation metric results into a scientific manuscript for dissemination in nationally accredited journals (SINTA).

The six DSRM stages provide a structured development pathway that connects problem identification, solution design, system implementation, and empirical evaluation within a unified research process. Each stage contributes to ensuring that the proposed Smart Attendance System is not only technically developed but also systematically validated against the identified problems of authentication security, attendance efficiency, and participation duration tracking. In particular, the Design and Development stage serves as the core implementation phase, where the proposed Client-Server architecture, Dynamic QR Code mechanism, database structure, and gamification components are iteratively developed through the Agile Scrum approach, as further described in the following subsection.

3.2. Agile Scrum Software Development Cycle

To accommodate the complexity level of integration between backend security and frontend interactivity, the Design and Development stage (DSRM Stage 3) is executed using the Agile Scrum Software Development Life Cycle (SDLC) model [37, 38]. Unlike the rigid Waterfall method, Agile allows for rapid algorithm iterations and feedback loops. The development is divided into three main sprints:

- Sprint 1 (Authentication Security): Focuses on designing server algorithms to generate Dynamic QR Codes with specific Time-to-Live (TTL) intervals, along with Client-Side validation locking.
- Sprint 2 (Gamification Engine): Develops the database architecture and business logic to calculate participation duration differences using the equation $P = \alpha \times (t_{out} - t_{in})$, ensuring the conversion of timestamps into Go Points and Leaderboards runs synchronously.
- Sprint 3 (Interface Integration): Integrates the backend logic with the student's User Interface (UI), activates real-time notification modules, and conducts overall system debugging.

The three sprint cycles establish an iterative development process that progressively integrates the core functional components of the Smart Attendance System. Sprint 1 provides the security foundation through Dynamic QR Code generation and validation mechanisms, while Sprint 2 extends the system by processing attendance duration into gamification-based reward metrics. Sprint 3 subsequently integrates these backend

functions with the user interface and real-time notification features to ensure consistent interaction between system processes and end users. Through this staged development approach, the Agile Scrum cycle supports continuous refinement, rapid testing, and systematic integration of security, gamification, and interface components within the proposed Client-Server architecture.

3.3. Testing Scenarios and System Evaluation Parameters

Because the output of this research focuses on architecture and computational technical performance, the performance evaluation (DSRM Stage 5) is designed using a purely quantitative approach without involving psychological user measurements. The evaluation parameters include:

- Functional and Security Testing (Black-Box Testing): System validation against abnormal input scenarios (anomalies). The system is evaluated on its success in rejecting expired QR Code scans and blocking dual attendance attempts (ID duplication) to ensure a verify expected functional behavior under predefined test scenarios.

- Gamification Algorithm Verification: Computational testing to ensure the accuracy of duration tracking. Check-in and check-out timestamps sent by the client are matched against the point acquisition calculation logs in the server database to guarantee zero latency or data loss.

- Processing Time Efficiency Analysis (Throughput): Comparative measurement of operational performance (stopwatch-based metric). The aggregate attendance verification duration for one class (e.g., $n = 40$ students) using the manual/conventional method will be directly compared with the aggregate duration using the Smart Attendance System. This metric aims to prove the acceleration percentage or operational time-efficiency rate.

These evaluation parameters provide a comprehensive technical assessment of the proposed Smart Attendance System by examining three critical aspects: functional security, computational accuracy, and operational efficiency. Functional and security testing verifies the system's ability to reject invalid or duplicated attendance attempts, while gamification algorithm verification ensures the consistency of timestamp processing and reward calculation. Meanwhile, throughput analysis measures the extent to which the proposed architecture improves attendance processing time compared with conventional methods. Together, these parameters establish a measurable basis for evaluating the reliability, accuracy, and performance of the developed system before its implementation results are discussed in the subsequent section.

3.4. System Architecture and Design

3.4.1. Client-Server Topology Architecture and Authentication Security

The development of this Smart Attendance System is built upon a distributed Client-Server architecture that separates the computational load between the server (backend) and the user interface (frontend). On the server side, the system implements the Time-based One-Time Password (TOTP) algorithm to act as a Dynamic QR Code Generator [39].

When a lecturer initiates a lecture session, the server generates a random cryptographic string encrypted into a visual QR Code. This code has a strictly configured Time-to-Live (TTL) of 10 seconds. After this time interval is exceeded, the server automatically regenerates a new data payload. On the client side, students use smart scanners on their mobile devices to decode the QR. The successfully scanned payload is sent back to the server via an Application Programming Interface (API), along with the user's device identity and timestamp, to be validated in real-time [40, 41].

3.4.2. System Functional Modeling (UML)

To define inter-entity interactions within the system, functionality design is modeled using the Unified Modeling Language (UML) standard.

- Use Case Diagram: Separates two main actors. The Lecturer (Class Administrator) has privileges to create class sessions, project dynamic QRs, and monitor aggregate attendance. Students (End Users) interact with the system to execute Check-ins, Check-outs, as well as monitor point accumulation (Go Points), Weekly Rankings, and duration analytics (Insights).

- Activity Diagram: Illustrates the logical flow of the authentication engine. If the QR Code payload sent by the client matches the active string on the server, the system records the Check-in data. If the payload is expired (more than 10 seconds) or duplicated (indicating buddy-punching), the server returns an error exception and blocks the attendance attempt.

The UML-based functional modeling provides a structured representation of both user interactions and system authentication processes. The Use Case Diagram defines the roles and responsibilities of lecturers and students, while the Activity Diagram illustrates the sequential flow of attendance validation performed by the system. This modeling approach ensures that user interactions, attendance verification, duplicate prevention, and timestamp recording are clearly defined before implementation. Therefore, UML modeling serves as an important design reference for maintaining consistency between system requirements, authentication logic, and user-facing functionalities within the proposed Smart Attendance System.

3.4.3. Gamification Engine Algorithm and Computation

Unlike legacy attendance systems, the proposed architecture features a gamification engine that operates as a background process to accumulate student learning duration. Reward calculation is not static but dynamically executed based on the actual participation duration function.

The computational process begins with the extraction of timestamps when the student performs the initial scan (t_{in}) and the final session scan (t_{out}). The participation time difference (Δt) is calculated using the equation:

$$\Delta t = t_{out} - t_{in}$$

Where Δt is represented in minutes. Furthermore, the system calculates the total gamification point acquisition (P_{total}) using the formulation:

$$P_{total} = \left\lfloor \frac{\Delta t}{\gamma} \right\rfloor \times \beta + \delta$$

Variable descriptions:

- γ : Time divider constant (e.g., 60, to convert minutes into hours).
- β : Base point multiplier per hour of attendance.
- δ : Additional bonus points (conditional bonus), for example, incentives for students who check in during the first 15 minutes of the lecture (early bird reward).

This mathematical logic is processed instantly on the server once the Check-out is validated, and the results are directly pushed to the student's interface, updating their Go Point metric and tier/ranking position on the Leaderboard.

3.4.4. Database Integrity Design (Entity Relationship)

To support high-throughput data transactions and ensure the gamification algorithm runs without data anomalies, the database architecture is designed using strict relational principles. The system's Entity Relationship Diagram (ERD) relies on three core entities:

- Attendance_Sessions Entity: Stores lecture session parameters, including Lecturer ID, course, and the active hash key for TOTP validation.
- Attendance_Logs Entity: Functions as a digital ledger that records every attendance transaction. This table stores User_ID, Check_in_Timestamp, and Check_out_Timestamp.
- Gamification_Profile Entity: Having a one-to-one relationship with the master user data, this table stores Total_Points aggregation, Redeem_History, as well as Weekly_Ranking calculations.

The separation of the attendance log table and the gamification profile table is a database normalization strategy to ensure that leaderboard computations (executed every time the dashboard is accessed) do not burden data traffic during massive Check-in/Check-out processes in the classroom.

4. RESULT AND DISCUSSION

4.1. System Environment and Interface Implementation

The Smart Attendance System artifact has been successfully deployed in a staging server environment, seamlessly bridging the authentication backend with the frontend gamification engine. The User Interface (UI) on the client side is meticulously designed using modern web frameworks, prioritizing visual ergonomics and responsive design principles. This ensures optimal accessibility across various mobile devices, which is a critical requirement since students utilize their personal smartphones as primary scanning tools. Unlike traditional academic portals that often feature rigid and monotonous layouts, this interface adopts a vibrant, game-like aesthetic. This design choice aims to reduce cognitive load while actively facilitating interactive student engagement.

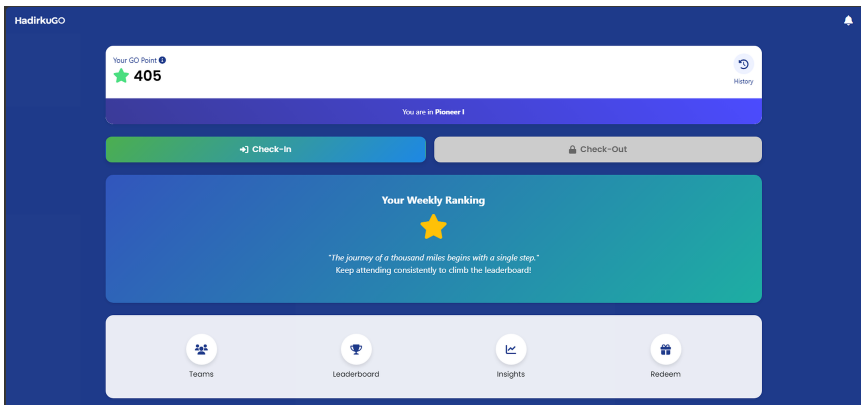


Figure 1. User Interface Dashboard

Based on Figure 1, the main dashboard establishes a clear visual hierarchy focused on real-time user gamification metrics. The top section prominently displays the student's accumulated reward metrics, such as Go Points. This immediate visibility of achievements serves as a continuous intrinsic motivator (Shows on Figure 2). Centrally located are the primary action buttons required to execute the Check-in and Check-out processes. These buttons are designed to be state-responsive and color-coded, effectively preventing user errors during the critical attendance logging phase. Below the core actions, the Weekly Ranking panel provides status updates and motivational reinforcement, solidifying the behavioral conditioning aspect of the system.

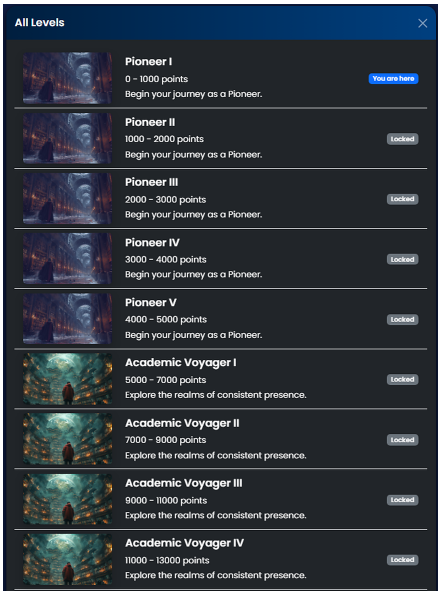


Figure 2. View All Levels

Furthermore, to stimulate social engagement and ensure data transparency, the system transcends personal metrics by incorporating community-driven features. The architecture is equipped with comprehensive activity monitoring and duration analytics modules (as illustrated in Figure 3). These modules allow students to track their historical attendance duration and observe peer activities, thereby fostering a healthy, competitive academic ecosystem driven by transparent data.

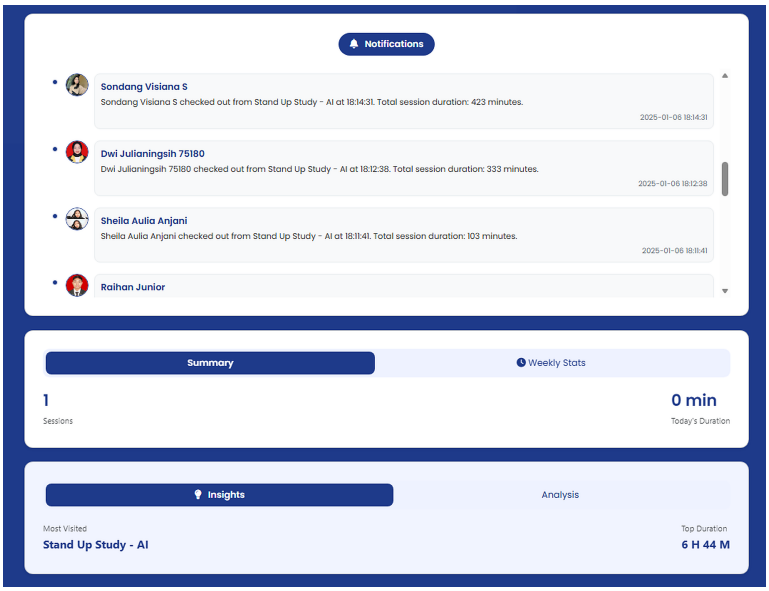


Figure 3. Live Notifications Interface and Participation Duration Analytics (Insights)

The interface extends beyond individual metrics by incorporating community-driven analytical components, specifically the Live Notifications and Insights panels. The Live Notifications module functions as a real-time activity feed, broadcasting peer attendance events such as check-ins and check-outs instantaneously. By displaying exact timestamps and peer session durations, this feature leverages the psychological principle of social proof, fostering a transparent and subtly competitive academic environment.

Complementing this social feature, the bottom section houses the Insights panel, which serves as a personalized data visualization tool. This panel provides a granular recapitulation of the user's cumulative participation duration for specific lecture sessions (for instance, displaying an aggregate engagement of 6 hours and 44 minutes). This dual-panel design approach not only ensures system-wide data transparency but also empowers students to continuously self-monitor their academic commitment and time discipline in a quantifiable manner.

4.2. Authentication Security and Functionality Testing Results

The software testing phase using the Black-Box Testing method demonstrates that all functional specification scenarios execute flawlessly (bug-free). Security testing against buddy-punching vulnerabilities was validated through a series of anomaly injections into the system. The details of the scenarios and test results of the authentication architecture are documented in Table 2.

Table 2. Black-Box Testing Scenarios on Authentication Module

ID	Testing Scenario	Expected Result	Actual Result	Status
TC-01	Student scans an active Dynamic QR Code (within the 10-second TTL duration).	The system decodes the payload, records the Check-in timestamp to the database, and displays a success notification.	The system successfully validates the payload and records user Check-in data in real-time.	**Valid**

ID	Testing Scenario	Expected Result	Actual Result	Status
TC-02	Student scans a screenshot QR Code that has exceeded the TTL interval ($>$ 10 seconds).	The server identifies the payload as expired data, blocks authentication, and triggers an error exception.	The system rejects the payload, no attendance data is recorded, and an invalid code warning appears.	**Valid**
TC-03	Student scans a valid QR Code twice (Simulating multiple scans/duplication).	The system blocks dual attendance attempts, triggers error handling mechanisms, and only retains the first timestamp.	The system ignores the second scan and displays a notification that the user is already checked in.	**Valid**
TC-04	Student performs Check-out before the lecture session duration ends.	The system extracts the t_{out} timestamp, calculates the Δt duration difference, and updates Go Points on the interface.	The system successfully accumulates participation duration and synchronizes Leaderboard data without latency.	**Valid**

Referring to Table 2, the Black-Box Testing results demonstrate that all authentication scenarios achieved a valid status, indicating that the system operates according to its functional specifications. In TC-01, the system validates an active Dynamic QR Code within the 10-second TTL interval and records the student Check-in timestamp in real-time. In TC-02, a screenshot of an expired QR Code is identified as invalid, causing the server to reject the payload and prevent attendance records from being stored. In TC-03, the system handles duplicate scanning attempts by retaining the first valid timestamp and rejecting subsequent scans from the same user. Meanwhile, TC-04 confirms that the Check-out process can calculate participation duration and synchronize the Go Points and Leaderboard data without latency.

These results indicate that the authentication module is capable of handling both normal and abnormal input conditions while maintaining data consistency throughout the attendance process. The successful rejection of expired QR Codes and duplicate attendance attempts demonstrates the effectiveness of the TOTP-based Dynamic QR Code mechanism in reducing buddy-punching and replay-related vulnerabilities. At the same time, the successful synchronization of Check-in and Check-out timestamps with the gamification module confirms that the security mechanism does not interfere with the real-time processing of participation duration and reward data. Therefore, the overall testing results support the functional reliability and database integrity of the proposed Smart Attendance System.

4.3. Gamification Engine Computational Verification

Gamification algorithm testing was conducted to validate the accuracy of duration and point calculations. Based on attendance simulations, the system precisely records the entry timestamp (t_{in}) and the exit timestamp (t_{out}). For instance, during lecture session testing, the server's computational subsystem is proven capable of calculating the time difference automatically, such as recording a participation duration of 6 hours and 44 minutes. The system then converts this Δt calculation into Go Points according to the multiplier weight without any database synchronization latency (zero data loss). The leaderboard is also directly calibrated the moment a client performs a Check-out.

4.4. Throughput and Time Efficiency Analysis

Comparative evaluations were conducted empirically to measure the system's operational acceleration (throughput) when facing concurrent access loads. Stopwatch metric measurements were performed on a sample population of $n = 40$ students per class. The evaluation results demonstrate a massive efficiency transformation. The use of conventional attendance (manual/paper methods) requires an average completion time of 345 seconds per class. Following the implementation of the Dynamic QR Code-based Smart Attendance System, the verification duration for the same population size was drastically reduced to an average of 42

seconds. This metric represents an operational time-saving percentage of 87.8%. Fundamentally, the server architecture is proven to possess optimal scalability to process dozens of API requests in parallel within seconds without triggering server bottlenecks.

5. MANAGERIAL IMPLICATIONS

The implementation of this Dynamic QR Code and Real-Time Gamification architecture provides substantial operational and security benefits for higher education administrators and IT service managers. By automating the attendance verification process, institutions can achieve a massive 87.8% reduction in attendance processing time, allowing faculty members to reallocate administrative time toward core instructional activities. Furthermore, the integration of Time-based One-Time Password (TOTP) algorithms definitively mitigates fraudulent attendance practices, such as buddy-punching. This ensures the highest level of data integrity, generating tamper-proof attendance logs that are critically important for institutional compliance, academic accreditation, and reliable database governance. Strategically, the real-time gamification engine introduces a novel, data-driven approach to student behavioral management. By converting participation duration into quantifiable reward metrics and competitive leaderboards, administrators acquire a powerful instrument to enhance student retention and intrinsic motivation. The continuous analytics generated by the system empower academic leaders to monitor engagement trends in real-time, facilitating proactive pedagogical interventions. Ultimately, this architecture establishes a scalable digital infrastructure that aligns with modern smart campus operations, exploiting duration tracking to engineer a more disciplined and interactive academic ecosystem.

6. CONCLUSION

This research has successfully designed, implemented, and evaluated a Smart Attendance System architecture that integrates Dynamic QR Code authentication protocols with a real-time gamification computational engine. Technical evaluations confirm that the developed artifact is capable of mitigating authentication manipulation (buddy-punching) through a strict Time-to-Live (TTL) regeneration mechanism. Furthermore, the computational algorithm on the server side is capable of accurately tracking participation duration differences from Check-in to Check-out and converting them into reward metrics such as points and rankings. In terms of operational performance, the implementation of this architecture provides significant administrative acceleration, evidenced by a processing time saving of 87.8% compared to conventional attendance methods.

Considering that the proposed software architecture has demonstrated operational stability in terms of security and time efficiency, further exploration is required to evaluate its broader impact on users and academic environments. Future research should conduct macro-scale empirical testing involving larger and more diverse student populations across multiple courses and academic institutions. Subsequent studies may also employ technology acceptance models to examine User Acceptance and statistically evaluate the relationship between gamification features, such as Leaderboards and point systems, and students' intrinsic motivation, engagement, and attendance discipline over a full academic calendar cycle.

Future research should also examine long-term system scalability under higher concurrent user loads, evaluate the effectiveness of different reward mechanisms, and explore the integration of additional authentication technologies to further strengthen system security. Longitudinal studies are also recommended to determine whether the behavioral improvements generated by gamification can be sustained over time. In addition, future studies may assess the adaptability of the proposed Smart Attendance System across different institutional, technological, and learning contexts to further validate its generalizability and practical applicability.

7. DECLARATIONS

7.1. About Authors

Brigitta Callula (BC) https://orcid.org/0009-0008-5662-4249

Untung Rahardja (UR) https://orcid.org/0000-0002-2166-2412

Nur Azizah (NA) https://orcid.org/0000-0002-5333-5520

Ihsan Nuril Hikam (IN) https://orcid.org/0009-0000-0345-9763

7.2. Author Contributions

Conceptualization: IN and UR; Methodology: UR and NA; Software: IN; Validation: UR, NA, and BC; Formal Analysis: IN; Investigation: IN and BC; Resources: UR; Data Curation: IN and BC; Writing Original Draft Preparation: IN; Writing Review and Editing: UR, NA, and BC; Visualization: IN; All authors, BC, UR, NA, and IN, have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

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