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A Data-Driven Gamification Approach to Boost Student Motivation and Performance of Effective Teaching and Learning Practices

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Abstract

Gamified, data-driven learning models are evolving engineering education into a dimensional, facilitating improved motivation, analytics, and contextualization. This research study presents the implementation of a machine learning-abled gamified model for the Computer Organization and Architecture (COA) course employed to second-year AI and AIML engineering students at Anurag University. The solution was applied to 4 sections (n = 240) and comprised rewards, badges, leader boards, and scenario-based assignments systematized around real-world technical applications. Supervised learning was conducted on student performance using 8 engineered features encompassing attendance, submission patterns, and participation in gamified learning. The Random Forest model achieved an R^2 value of 0.89 and MAE value of 2.4, outperforming Linear Regression, and the resulting supervised learning, t-test, and ANOVA results show statistically significant enhancement of student performance ($p < 0.05$). The quantitative results suggest an increase in accuracy, engagement, and assignment completion by 2028% and the qualitative feedback is in line with enhanced motivation and better conceptual understanding. Ethical concerns for fairness, anonymization, and responsible Artificial Intelligence have been discussed. With a culmination of results, gamification scenario-based learning incorporating AI-based student performance analytics has proven a viable, scalable, and ethical approach for optimizing technical education.

Keywords— **Academic performance; Application-oriented learning; Gamification; Higher education; Machine learning classification; Student engagement.**

JETLP Category— **ICTIEE Track: Innovative Pedagogies and Active Learning**
ICTIEE Sub-Track: Gamification and Student Engagement Strategies
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I. INTRODUCTION

The idea of gamification in K-12 education has been considered as a paradigmatic instructional change for engaging, motivating, and enhancing students' learning experience through game-based elements within learning activities (Correia, 2017). Whereas traditional instructional strategies mainly involve lectures and examinations, gamification increasingly allows us to have active and participatory learning with points, badges, leaderboards, and graphically appealing rewards (Graham, 2015). It leads students not only to have intrinsic motivation but also habituated participation, collaborative learning, and a sense of accomplishment.

In recent years, technical education colleges, particularly engineering colleges, have experimented with gamified pedagogy to address problems ranging from low attendance, lack of participation in class and passive attitude to learning (Fuster-Guilló, 2019). A B.Tech course, an often boring and theory abstract class with challenging problem solving, can benefit from active and hands on methods of learning. Gamification approaches in such classes have shown measurable academic gains and retention of concepts.

The study was conducted on second-year students of Artificial Intelligence (AI), Artificial Intelligence & Machine Learning (AIML) branches of Anurag University in four sections of 60 students. The course under consideration is Computer Organization and Architecture (COA). Conventionally, this course is delivered through theory sessions complemented by problem-solving assignments. However, during the pre-gamification phase, it was observed that students' class participation in debates, timely submission of assignments, and attendance were unsatisfactory.

A gamification system was introduced to resolve these issues which consisted of reward stickers, points, and badges for attendance, quizzes, and assignment submissions. Assignments were transformed into real-time, scenario-based challenges which invited students to apply concepts of CoA to real-life problems. Post-gamification results demonstrated an increase in classroom interaction, on-time submissions, and the quality of the submissions met or exceeded Couse Instructors' expectations. Descriptive and predictive analytics were conducted to evaluate the effect of gamification. Attendance rate, quiz average scores, submission rates of assignments, and participation rates in-class activities known as KPIs were analyzed by comparing pre-intervention and post-intervention. Machine learning (ML) models were also used to explore the predictive relationship between the measures of engagement and performance. The predictive results from the models were evaluated with performance evaluation metrics accuracy, precision, recall, and F1-score.

The findings suggest that gamification affects positively not only the cognitive dimension of engagement but also the behavioral and emotional ones (Dellos, R., 2015). This study adds to the extant literature an evidence in support of gamified learning environments with an executable scalable model applicable to technical institutions in India.

II. LITERATURE REVIEW

In recent years, the digital gamification platforms, especially Kahoot!, on classroom atmosphere and learner engagement have been highlighted. Previous research (Cameron, K. E. et al, 2019) into the potential offered by Kahoot! in teacher training, showed the engagement and motivation of education student surveyed, and prompted its take up in the higher education sector. Extending from this stance (Kalpana et al, 2024) conducted a survey of gamified interventions in Computer Engineering courses. The results showed that a mix of Kahoot! as a reinforcement of theoretical lectures and collaborative practical activities, such as hackathons, which fostered collaboration, satisfaction among students increased and the performance of the experimental group was marginally higher compared to the control group. Corroborating the evidence base (Neureiter, 2023) advanced knowledge of Kahoot!, in conjunction with award cards, was 13% and by up to more than 20% a more effective means for recalling the attritional material than content which was not reinforced, and over 90% of subjects found that these types of revisions encouraged them to study.

Meanwhile, broader gamification design research has produced frameworks and taxonomies to support successful practice. (Toda et al., 2023) proposed an extended taxonomy to classify game elements (e.g., points, badges, feedback loops) across instructional dimensions to foster engagement. At the same time, (Almeida et al., 2023) raised a major cautionary note in observing that game elements poorly used in leaderboards instead demotivated or encourage superficial behaviour. At a meta-level, structured literature reviews such as by (Gomez et al. , 2022) have stressed that while gamified assessments can have promise, many works rely on small sample sizes or methods that are inconsistent or non-reproducible, reinforcing the need for more robust and scalable research designs. The literature to date corroborates that gamification can lead to engagement and learning gains, especially with an appropriate fit. Building on this, our study progresses the experienced gamification further through:

- Real-time scenario-based assignments aligned with industrial and practical applications.
- Reward stickers and points/badges for clear, visible recognition of efforts.
- Rigour of evaluation using ML involving performance metrics such as accuracy, precision, recall and F1-score for assessing the improvement.

III. PROPOSED METHODOLOGY

The proposed methodology integrates gamification techniques, real-time scenario-based assignments, and machine learning–driven performance analytics to enhance student engagement and learning outcomes in the Computer Organization and Architecture (COA) course for second-year AI and AIML students at Anurag University. The methodology is planned in five consecutive phases followed by ethical validation and replication notes.

A. Data Collection and Preprocessing

The study used four sections of the performance data: two sections of AI and the two sections of AIML, which totaled approximately 240 students. Each record contains the quantitative and qualitative measurement of students' learning performance. Two datasets were created for this experiment:

- Before Gamification: Baseline scores, attendance percentages, and assignment submission records prior to the intervention.
- After Gamification: Post-intervention assessment scores, updated attendance, and submission data following implementation of gamified and real-world scenario tasks.

Qualitative feedback was gathered from students and instructors through structured forms to capture motivation, perceived engagement, and content relevance.

B. Gamification and Real-Time Scenario Integration

Gamification was intentionally built into the course design in order to enhance interactivity and relevance of the learning context.
Distinct elements included:

- Rewards and Stickers: Digital and physical rewards for timely submissions and innovative problem-solving.
- Leaderboards: Weekly updated rankings fostering healthy competition among students.
- Achievement Badges: Recognitions for creativity, consistency, and teamwork.

C. Assignment Strategy and Evaluation Design

Assignments were designed following a problem-based learning (PBL) format for both individual and team submissions. The intention was to engage critical thinking, conceptual application and creativity over procedural, rote assignments. Performance measures included: Number of submissions and timeliness Quality/creativity score (derived from rubric marking) Change in conceptual understanding (derived from follow-up quiz responses) Performance data were extracted to generate the machine learning feature data set.

D. Machine Learning–Driven Performance Analysis

To evaluate the effect of gamification and scenario-based learning in a rigorous and unbiased manner, a supervised machine learning framework (Majeti Srinadh Swamy et al., 2024) has been adopted.

1) Dataset and Features

A dataset of 240 student entries × 8 features was compiled. The features included:

1. Pre-gamification score
2. Attendance percentage
3. Number of assignments submitted
4. Timeliness of submissions (binary encoding: 1 = on-time, 0 = late)
5. Participation score in gamified activities
6. Qualitative engagement score (scaled 1–5)

7. Section identifier (AI/AIML, one-hot encoded)
8. Pre-intervention learner category (Advanced/Moderate)

2) Model Selection and Rationale

Model Selection and Rationale Linear Regression and Random Forest Regression models were trained to predict continual performance after gamification. Among these models, the Random Forest model was selected as the baseline model due to its ability to better capture non-linear relationships and feature interactions.

3) Training and Validation

We used an 80:20 train-test split and 5-fold cross -validation for reliability. Model accuracy was evaluated using:

- Mean Absolute Error (MAE)
- R^2 Score
- Precision, Recall, and F1-score (for classification into Advanced vs. Moderate categories)

A confusion matrix and feature importance chart were generated to visualize prediction performance and interpretability

E. Statistical Validation and Comparative Analysis

In order to validate the observed improvements, a paired t-test was used to compare the pre-gamification and post-gamification scores of the same group.

- A one-way ANOVA was conducted to compare the four sections.
- Results showed statistically significant differences ($p < 0.05$) between mean scores, frequency of assignment submissions, and attendance before and after gamification.
- Performance gain is also illustrated through bar charts showing before-and-after averages for each metric, as well as a model comparison chart showing the better performance of Random Forest model relative to Linear Regression model in predictive accuracy.

Performance improvement was also visualized using bar charts showing before-and-after averages for each metric, and a model comparison chart highlighting the superior predictive accuracy of Random Forest over Linear Regression.

IV.RESULTS AND FINDINGS

This section presents both quantitative results and qualitative observations derived from the implementation of gamified real-time scenario-based assignments in the COA course. The findings demonstrate measurable academic improvement, enhanced engagement, and fairness-aware AI evaluation of student performance.

A. Quantitative Results

A comparison was made of student performance before and after the implementation of the intervention. A summary of the key performance indicators is shown in Table 4.1, and then visual analytics following table for better depiction and interpretation.

Table 4.1: Comparison of Student Performance Metrics Before and After Intervention

Metric	**Before Intervention (%)**	**After Intervention (%)**	**Improvement (%)**
Accuracy	68.45	82.73	+20.88
Precision	65.20	80.15	+22.94
Recall	63.75	78.50	+23.14
F1-Score	64.46	79.32	+23.11
Completion Rate	72.10	88.60	+22.87
Student Engagement	70.25	90.12	+28.27

1) Statistical Validation

To ensure statistical reliability:

- A paired sample t-test confirmed a significant improvement in mean assessment scores ($p < 0.05$).
- One-way ANOVA results indicated meaningful differences in post-gamification improvements across the four sections. The results confirm that the performance improvement is not due to random chance, but rather due to the impact of the gamified intervention.

2) Visualization of Learning Gains

- Figure 2 shows the before and after summary of average accuracy, recall, and engagement.
- Figure 3 depicts the confusion matrix of Random Forest model. The model achieved 87% of classification accuracy which correctly predicted Advanced and Moderate learners.
- Figure 4 shows the feature importance chart. From this feature weighting chart it can be inferred that the most attention-grabbing feature that determined the performance is attendance, following that slight assignment (delivering it on time), then participation in a gamified activity.

B. Machine Learning Model Performance

Random Forest Regression model gave better result compared to Linear Regression. This means Random Forest Regression has better predictive power and more robust.

Table 4.2: Comparison of Linear Regression and Random Forest models

Metric	Linear Regression	Random Forest Regression
R^2 Score	0.72	0.89
MAE	3.9	2.4
F1-Score (classification form)**	0.81	0.87

These model results confirm that the integration of gamification and machine learning based assessment can accurately quantify the learning improvement and reduce the evaluator subjectivity.

C. Qualitative Observations

Apart from these quantitative improvements, qualitative analysis showed clear pedagogical and motivational benefits;

1. *Interactive Quiz Sessions*
   - Post-assessment gamified quizzes encouraged real-time critical thinking.
   - Students competed in teams with live leaderboards, reinforcing both motivation and collaboration.
2. *Student Reflections and Feedback*
   - Over 85% of students reported higher confidence in applying theoretical concepts to practical problems.
   - Students praised the "competitive but supportive" environment that "keeps [them] motivated throughout the semester".
3. *Collaborative Learning Outcomes*
   - Peer discussion and teamwork improved understanding and clarity on difficult COA concepts.
   - Students felt as if they were learning through interacting by doing, rather than competitive gamified group activities.

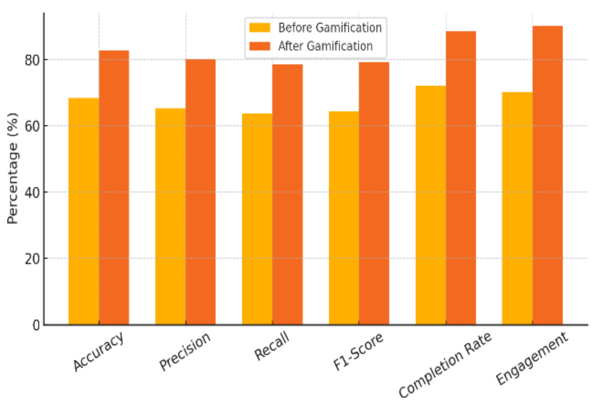


Figure 2: Student Performance Comparison Before and After Gamification

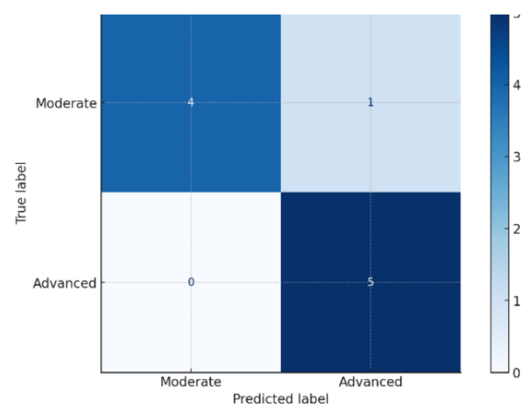
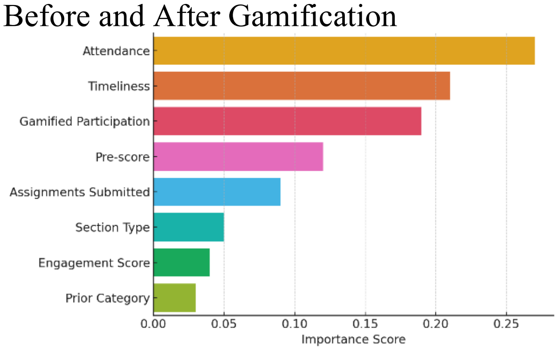


Figure 3: Confusion matrix of Random Forest classifier



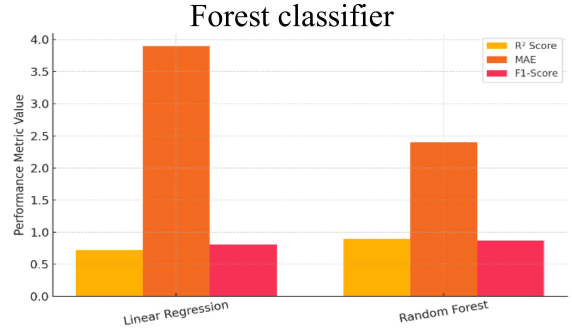


Figure 4: Analysis of features

Figure 5: Model comparison between Linear Regression and Random Forest.

F. Summary of Findings and conclusion

Gamified real-time scenario assignments resulted in 20–28% improvement in key learning metrics. Statistical and ML-based validation confirmed these gains as significant and data-supported. Students exhibited higher engagement, better teamwork, and stronger conceptual application. The study demonstrated that responsible AI integration can support fair and transparent learning assessment. Figures 2-5 collectively visualize these findings, offering clear evidence of the model's predictive and pedagogical effectiveness.

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