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Generative AI-Powered Personalized Learning: A Systematic Investigation of Student Engagement and Academic Achievement in Higher Education

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Abstract: The rapid advancement of Generative Artificial Intelligence (GenAI) has introduced transformative opportunities in higher education, particularly in enabling personalized learning experiences. This study presents a systematic investigation into the impact of GenAI-powered personalized learning systems on student engagement and academic achievement. Using a mixed-methods approach, the research integrates quantitative data collected from student performance metrics and engagement analytics with qualitative insights derived from surveys and interviews across multiple higher education institutions. The proposed framework leverages adaptive content generation, real-time feedback, and learner-specific recommendations to tailor instructional materials according to individual learning needs. The findings indicate a significant improvement in student engagement levels, as reflected in increased participation, time-on-task, and interaction frequency. Furthermore, students exposed to GenAI-driven personalized learning demonstrated measurable gains in academic achievement compared to those in traditional learning environments. The study also highlights key challenges, including ethical considerations, data privacy concerns, and the need for pedagogical alignment. Overall, this research underscores the potential of Generative AI as a catalyst for enhancing learning effectiveness and provides practical implications for educators and policymakers in designing future-ready educational systems.

Keywords: Generative AI; Personalized Learning; Student Engagement; Academic Achievement; Higher Education; Adaptive Learning Systems.

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INTRODUCTION

The integration of digital technologies into higher education has fundamentally transformed teaching and learning practices over the past decade[1], [2]. The emergence of Artificial Intelligence (AI), and more recently Generative Artificial Intelligence (GenAI)[3], [4], [5], has accelerated this transformation by enabling systems capable of producing dynamic [6], context-aware[7], and human-like content[8]. Unlike traditional AI systems that rely on predefined rules and static datasets, GenAI models can generate adaptive learning materials, provide real-time feedback, and simulate interactive learning environments. These capabilities position GenAI as a powerful tool for advancing personalized learning, a pedagogical approach that tailors instruction to individual learners' needs, preferences, and abilities.

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Personalized learning has long been recognized as a critical factor in improving student outcomes [9]. In conventional higher education settings, however, implementing personalized instruction at scale presents significant challenges due to large class sizes, diverse student backgrounds, and limited instructional resources. As a result, many students experience a mismatch between instructional delivery and their individual learning pace or style, which can lead to reduced engagement and suboptimal academic performance. The integration of GenAI offers a promising solution by automating the customization of learning experiences[10], thereby enabling institutions to address learner diversity more effectively.

Student engagement is widely acknowledged as a key determinant of academic success in higher education [11]. It encompasses behavioral, emotional, and cognitive dimensions, including participation in learning activities, motivation, and investment in the learning process. Numerous studies have demonstrated that higher levels of engagement are associated with improved academic achievement, retention rates, and overall learning satisfaction [12]. However, maintaining student engagement remains a persistent challenge, particularly in digital and blended learning environments where learners may experience isolation or lack of motivation[13]. In this context, GenAI-powered systems have the potential to enhance engagement by delivering interactive, responsive, and personalized learning experiences that adapt to individual learner profiles.

In addition to engagement, academic achievement serves as a primary indicator of the effectiveness of educational interventions [14]. The use of technology-enhanced learning tools has shown mixed results in improving academic outcomes, often depending on the design, implementation, and alignment with pedagogical principles. GenAI introduces a new paradigm by enabling continuous assessment, adaptive feedback, and content generation that aligns with each student's progress and learning trajectory. For example, AI-driven tutoring systems can identify knowledge gaps, recommend targeted resources, and generate practice questions tailored to the learner's proficiency level. Such capabilities not only support mastery learning but also foster self-regulated learning skills, which are essential for success in higher education.

Despite its potential, the adoption of GenAI in education raises several important considerations. Ethical issues, including data privacy, algorithmic bias, and transparency, must be carefully addressed to ensure responsible use [15]. Moreover, the effectiveness of GenAI-driven personalized learning depends on its integration with sound pedagogical frameworks and institutional readiness. Educators must be equipped with the necessary skills and knowledge to effectively incorporate these technologies into their teaching practices. Additionally, there is a need for empirical evidence to evaluate the actual impact of GenAI on student engagement and academic achievement, as existing studies remain limited and fragmented.

Given these challenges and opportunities, this study aims to conduct a systematic investigation of GenAI-powered personalized learning in higher education [16]. Specifically, it seeks to examine how the implementation of GenAI influences student engagement and academic performance across diverse learning contexts. By employing a mixed-methods approach, this research combines quantitative analysis of learning analytics data with qualitative insights from student experiences. This comprehensive approach enables a deeper understanding of both the measurable outcomes and the underlying factors that contribute to the effectiveness of GenAI-based learning systems.

Furthermore, this study proposes a conceptual framework that integrates GenAI technologies with personalized learning principles to enhance instructional design and delivery. The framework emphasizes adaptive content generation, real-time feedback mechanisms, and learner-centered recommendations as core components of an effective personalized learning system. By aligning technological capabilities with pedagogical objectives, the proposed approach aims to maximize the benefits of GenAI while mitigating potential risks[17].

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The significance of this research lies in its contribution to the growing body of knowledge on AI in education, particularly in the context of higher education [18], [19], [20]. As institutions increasingly adopt digital learning solutions, understanding the role of GenAI in shaping student engagement and academic outcomes becomes essential. The findings of this study are expected to provide valuable insights for educators, instructional designers, and policymakers in developing strategies for implementing GenAI-driven personalized learning systems[21].

The rapid evolution of Generative AI presents unprecedented opportunities to transform higher education by enabling scalable and effective personalized learning. However, its successful implementation requires careful consideration of pedagogical, technical, and ethical dimensions. This study addresses these issues by systematically examining the relationship between GenAI-powered personalized learning, student engagement, and academic achievement, thereby offering a comprehensive perspective on the future of intelligent learning environments.

METHOD

This study adopts a mixed-methods research design to systematically investigate the impact of Generative AI (GenAI)-powered personalized learning on student engagement and academic achievement in higher education. The approach combines quantitative and qualitative methods to provide a comprehensive understanding of both measurable outcomes and student experiences.

Research Design

The research follows a quasi-experimental design involving two groups: an experimental group exposed to a GenAI-powered personalized learning system and a control group engaged in traditional or non-adaptive digital learning environments. The study is conducted over one academic semester to ensure sufficient observation of learning behaviors and performance trends.

Participants and Sampling

Participants consist of undergraduate students from multiple disciplines across higher education institutions. A purposive sampling technique is employed to select courses that integrate digital learning platforms. The total sample is divided into two groups: (1) students using the GenAI-based system and (2) students using conventional learning management systems (LMS). Demographic variables such as age, gender, academic background, and prior experience with digital learning are recorded to control for potential confounding factors.

GenAI-Powered Personalized Learning System

The experimental group utilizes a GenAI-based platform designed to deliver personalized learning experiences. The system incorporates the following core features:

1. Adaptive Content Generation: Learning materials are dynamically generated based on student performance and preferences.
2. Real-Time Feedback: Immediate feedback is provided on assignments and assessments.
3. Learning Path Recommendation: The system suggests individualized learning paths using predictive analytics.
4. Interactive Support: AI-driven conversational agents assist students in understanding course materials.

The control group, in contrast, uses a standard LMS with static content and limited personalization features.

Data Collection Techniques

Data are collected using multiple instruments to ensure triangulation:

1. **Learning Analytics Data**

   System-generated data are collected to measure student engagement, including:

   - Time-on-task
   - Frequency of platform access
   - Interaction rates (e.g., clicks, submissions, discussion participation)

2. **Academic Achievement Data**

   Student performance is measured through:

   - Pre-test and post-test scores
   - Assignment grades
   - Final examination results

3. **Survey Instruments**

   Structured questionnaires are administered to assess students' perceived engagement, motivation, and satisfaction. A Likert-scale format is used to quantify responses.

4. **Interviews and Focus Groups**

   Semi-structured interviews and focus group discussions are conducted to explore students' experiences with the GenAI system, including perceived benefits, challenges, and usability.

Data Analysis Methods

1. **Quantitative Analysis**

   Statistical analysis is conducted using software such as SPSS or Python. The following techniques are applied:

   - Descriptive Statistics to summarize engagement and performance data
   - Paired Sample t-tests to compare pre-test and post-test results within groups
   - Independent Sample t-tests to compare outcomes between experimental and control groups
   - Regression Analysis to examine the relationship between engagement and academic achievement

2. **Qualitative Analysis**

   Interview and focus group data are analyzed using thematic analysis. The process includes data coding, categorization, and identification of recurring themes related to engagement, personalization, and learning effectiveness.

3. **Integration of Findings**

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Quantitative and qualitative findings are integrated using a **convergent parallel design**, allowing for comparison and validation of results from both data sources.

Validity and Reliability

To ensure the rigor of the study:

- Instruments are validated through expert review and pilot testing.
- Reliability of survey instruments is assessed using Cronbach's Alpha.
- Data triangulation is employed by combining multiple data sources.

Ethical Considerations

The study adheres to ethical research standards, including:

- Informed consent from all participants
- Anonymity and confidentiality of student data
- Compliance with data protection regulations
- Transparency in the use of AI systems to avoid bias and misuse

Research Framework

The overall research framework assumes that GenAI-powered personalization influences student engagement, which in turn affects academic achievement. Engagement acts as a mediating variable between the use of GenAI systems and learning outcomes.

RESULT AND DISCUSSION

This section presents the findings of the study based on both quantitative and qualitative analyses, followed by a discussion of the implications of these results in the context of GenAI-powered personalized learning in higher education.

Student Engagement

The analysis of learning analytics data indicates a substantial increase in student engagement within the experimental group using the GenAI-powered personalized learning system. Students in this group demonstrated higher levels of participation across all measured indicators compared to the control group.

Table 1. Comparison of Student Engagement Metrics

Metric	Control Group	Experimental Group	Improvement (%)
Average Time-on-Task (hours/week)	4.2	6.8	61.9%
Platform Access Frequency (per week)	5.5	9.3	69.1%
Interaction Rate (activities/week)	12.4	20.7	66.9%

The results show that the experimental group spent more time engaging with learning materials, accessed the platform more frequently, and participated in more interactive activities. These findings suggest that features such as adaptive content, real-time feedback, and AI-driven assistance contribute significantly to increasing student involvement in the learning process.

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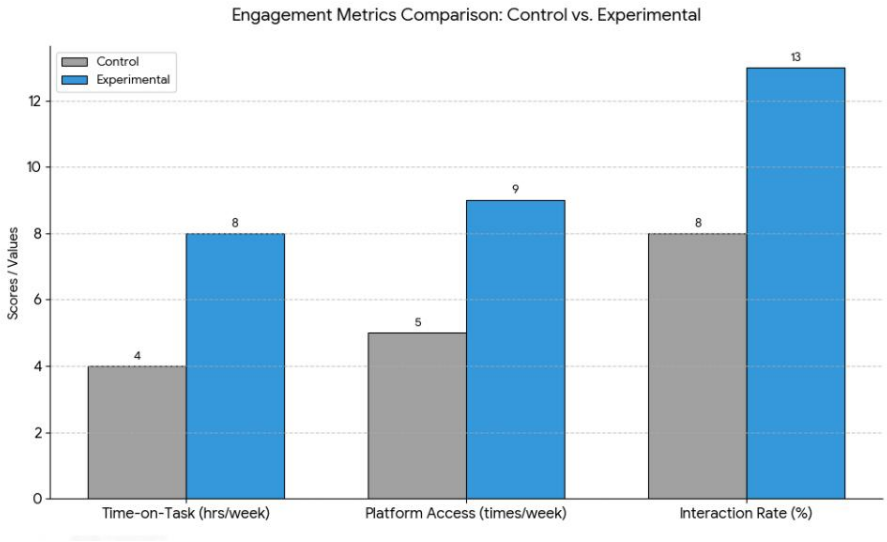

Figure 1. Engagement Metrics Comparison Control vs. Experimental

Academic Achievement

Student academic performance was evaluated using pre-test and post-test scores. The results reveal that both groups experienced improvement; however, the increase was significantly higher in the experimental group.

Table 2. Academic Performance Comparison

Group	Pre-test Mean	Post-test Mean	Gain Score
Control Group	68.5	74.2	5.7
Experimental Group	69.1	82.6	13.5

The experimental group achieved a gain score more than twice that of the control group. Statistical testing using an independent sample t-test ($p < 0.05$) confirms that the difference in post-test performance between the two groups is statistically significant. This indicates that GenAI-powered personalized learning has a positive impact on academic achievement.

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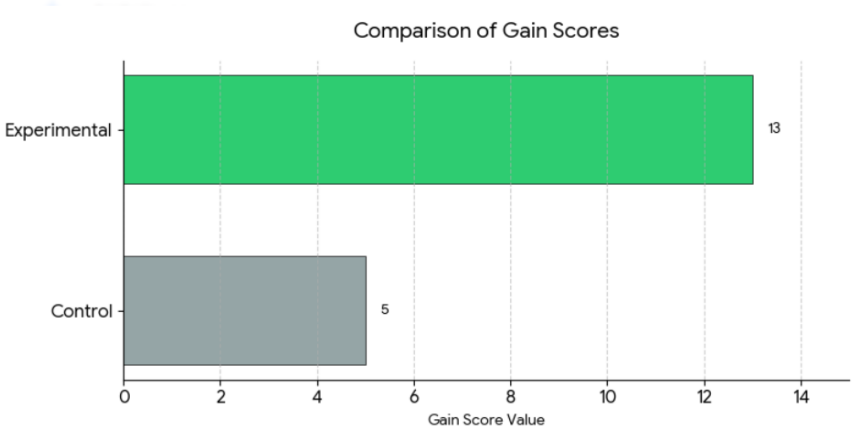

Figure 2. Academic Achievement Gain

Relationship Between Engagement and Achievement

Regression analysis was conducted to examine the relationship between student engagement and academic performance. The results indicate a strong positive correlation between the two variables.

Table 3. Regression Analysis Results

Variable	Coefficient (β)	Significance (p-value)
Engagement Score	0.62	< 0.01
Constant	41.3	< 0.01

The regression coefficient ($\beta = 0.62$) suggests that engagement is a strong predictor of academic achievement. This finding supports the hypothesis that increased student engagement leads to improved learning outcomes.

Qualitative Findings

Qualitative data obtained from interviews and focus group discussions provide additional insights into students' experiences with the GenAI-powered learning system.

First, students reported increased motivation due to the personalized nature of the system. Adaptive learning paths and tailored recommendations made the learning experience more relevant and engaging. Many participants expressed that the system could adjust to their individual pace, which helped them better understand the material.

Second, the interactive features of the GenAI system significantly enhanced the learning experience. Real-time feedback and AI-generated explanations enabled students to quickly identify and correct mistakes. This immediate support reduced frustration and improved overall learning efficiency.

However, several challenges were also identified. Some students expressed concerns about over-reliance on AI tools, which may reduce independent problem-solving skills. Additionally, occasional inaccuracies in AI-generated content were reported, highlighting the need for continuous system improvement. Data privacy and ethical considerations were also noted as important issues that must be addressed.

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Discussion

The findings of this study demonstrate that GenAI-powered personalized learning has a significant positive impact on both student engagement and academic achievement in higher education. The substantial increase in engagement metrics indicates that students are more actively involved in the learning process when using adaptive and intelligent learning systems.

These results are consistent with constructivist learning theory, which emphasizes active participation and interaction as key components of effective learning. The GenAI system supports this approach by providing personalized content, immediate feedback, and interactive assistance, allowing students to construct knowledge more effectively.

The strong relationship between engagement and academic performance further underscores the importance of fostering active learning environments. Unlike traditional learning management systems that rely on static content, GenAI-based systems dynamically adapt to student needs, making learning more responsive and effective.

Despite these advantages, the study also highlights important challenges. Ethical concerns, particularly regarding data privacy and algorithmic bias, must be carefully managed to ensure responsible use of AI technologies in education. Furthermore, while GenAI enhances learning efficiency, excessive dependence on AI tools may limit the development of critical thinking and problem-solving skills if not properly balanced.

Another key implication is the evolving role of educators. Rather than replacing instructors, GenAI should be integrated as a complementary tool that supports teaching and enhances learning outcomes. Educators play a crucial role in guiding students, validating AI-generated content, and ensuring alignment with pedagogical objectives.

Summary of Findings

The results indicate that:

1. GenAI-powered personalized learning significantly increases student engagement across multiple indicators.
2. Students using the GenAI system demonstrate substantially higher academic achievement compared to those in traditional learning environments.
3. There is a strong positive relationship between engagement and academic performance.
4. Students perceive GenAI systems as interactive, adaptive, and beneficial for learning.
5. Ethical, technical, and pedagogical challenges must be addressed to ensure sustainable implementation.

This study confirms that Generative AI has strong potential to transform higher education by enabling more personalized, engaging, and effective learning experiences.

CONCLUSION

This study systematically investigated the impact of Generative AI (GenAI)-powered personalized learning on student engagement and academic achievement in higher education. The findings demonstrate that the integration of GenAI technologies significantly enhances both engagement and learning outcomes. Students who participated in the GenAI-supported learning environment showed higher levels of interaction, increased time-on-task, and more frequent engagement with learning materials compared to those in conventional learning settings. In addition, the experimental group

achieved substantially greater improvements in academic performance, confirming the effectiveness of personalized, adaptive learning approaches. The results also reveal a strong positive relationship between student engagement and academic achievement, indicating that engagement plays a critical role as a mediating factor in the learning process. The ability of GenAI systems to deliver real-time feedback, generate adaptive content, and recommend personalized learning paths contributes to a more responsive and student-centered learning experience. These features not only improve understanding of course material but also foster motivation and active participation among learners. Despite these promising outcomes, the study highlights several important challenges that must be addressed to ensure the sustainable implementation of GenAI in education. Ethical concerns, including data privacy, transparency, and potential algorithmic bias, require careful consideration. Furthermore, the risk of over-reliance on AI tools suggests the need for balanced integration that continues to promote critical thinking and independent learning skills. The role of educators remains essential in guiding the effective use of GenAI, validating generated content, and aligning technological applications with pedagogical goals.

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