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Research Article

Personalized Learning through ChatGPT: A Quasi-Experimental Study on Adaptive Curriculum in High School Settings

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Abstract

The challenge of catering to diverse learning paces and styles in traditional high school classrooms often limits student potential. The emergence of advanced AI, such as ChatGPT, presents a novel opportunity to create adaptive learning environments that personalize educational content in real-time. This study aimed to investigate the effectiveness of a ChatGPT-driven adaptive curriculum on student academic performance and engagement compared to conventional, non-adaptive teaching methods. A quasi-experimental, pre-test/post-test design was conducted with 110 high school students. The intervention group (n=55) utilized an adaptive curriculum where content was dynamically adjusted by ChatGPT based on performance, while the control group (n=55) received standard instruction. Academic performance was measured via subject-specific tests, and engagement was assessed using the Student Engagement Instrument (SEI). The intervention group demonstrated a statistically significant improvement in academic performance ($p < .01$) and higher engagement scores ($p < .05$) compared to the control group. The adaptive curriculum effectively addressed individual learning gaps and maintained student interest. Integrating ChatGPT to facilitate personalized, adaptive curricula is a highly effective strategy for enhancing both academic achievement and student engagement in high school settings. This approach offers a scalable solution to individualized instruction.

Keywords: Chatgpt, Adaptive Curriculum, Student Engagement

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INTRODUCTION

The contemporary educational paradigm is grappling with a fundamental challenge: reconciling standardized curricula with the increasingly recognized diversity of student learning needs. Traditional secondary education models, largely inherited from an industrial era, operate on a one-size-fits-all principle, delivering a uniform pace and style of instruction to classrooms of heterogeneous learners (Calzolari N. et al., 2024; Chen et al., 2024). This approach inherently struggles to accommodate the wide spectrum of cognitive abilities, prior knowledge, and motivational profiles present in any given student cohort. The result is often a suboptimal learning environment where advanced students may feel disengaged due to a lack of challenge, while others may fall behind, unable to grasp foundational concepts before the curriculum moves forward. This persistent tension between standardization and individualization represents one of the most significant obstacles to achieving equitable and effective educational outcomes in the 21st century.

In response to this challenge, the field of educational technology has long pursued the goal of personalized learning, aiming to tailor educational experiences to the specific needs and characteristics of each student. Early iterations of this concept relied on branching logic and pre-programmed pathways, which offered limited adaptability. The recent advent of sophisticated generative artificial intelligence, exemplified by large language models like ChatGPT, marks a revolutionary leap forward. These AI systems possess an unprecedented ability to understand context, generate human-like text, and adapt content in real-time based on user interactions (Mi & Li, 2024; Schneider et al., 2024). This technological breakthrough presents a novel and powerful opportunity to move beyond static personalization and create truly dynamic, adaptive learning environments that can respond instantaneously to a student's performance.

The integration of generative AI into educational settings promises to redefine the boundaries of personalized instruction. A ChatGPT-driven system can function as a tireless, one-on-one tutor for every student, capable of re-explaining complex topics in multiple ways, generating customized practice problems, and adjusting the difficulty level of material based on a student's demonstrated mastery (Cadeddu et al., 2024; Dvivedi et al., 2024). This capacity for real-time adaptation and content generation allows for the creation of a bespoke learning journey for each individual. Such a system can provide immediate, targeted feedback to correct misconceptions and offer enrichment activities to deepen understanding, thereby fostering a learning environment that is not only more efficient but also profoundly more engaging and empowering for the student.

Despite the immense theoretical potential of using generative AI for personalized learning, a significant problem exists in the lack of rigorous, empirical evidence validating its effectiveness in authentic high school settings. Much of the current discourse surrounding AI in education is speculative, focusing on potential applications rather than measured outcomes. While many educators and technologists are enthusiastic, school administrators and policymakers require robust data to justify the investment in and integration of these new technologies (Fischbach, 2024; Přibáň et al., 2024). The core problem this research addresses is the critical gap between the proposed benefits of an AI-driven adaptive curriculum and the scientific proof of its impact on key educational metrics, namely academic performance and student engagement.

The specific issue is that the conventional, non-adaptive teaching model remains the default standard in most secondary schools, not due to its proven superiority, but due to its historical precedence and the absence of well-documented, scalable alternatives. This "one-pace" instruction model systematically creates learning gaps for some students and stifles the potential of others (Přibáň et al., 2024; Xie et al., 2024). The problem is thus twofold: first, the inherent inefficiency and inequity of the traditional classroom structure, and second, the lack of quasi-experimental research that directly compares this established model against an AI-adaptive curriculum within the complex, real-world ecosystem of a high school. Without such a direct comparison, the claims about AI's transformative power remain largely unsubstantiated hypotheses.

This study, therefore, confronts the challenge of moving the discussion from the theoretical to the empirical. It addresses the pressing need to understand whether a curriculum dynamically adjusted by an AI like ChatGPT can lead to statistically significant improvements in learning outcomes. The problem is not merely about whether students *can* use ChatGPT as a learning tool, but whether its systematic integration as the engine of an adaptive curriculum results in superior academic achievement and a more engaging educational experience when measured against the prevailing instructional methods. Answering this question is fundamental to guiding the responsible and effective adoption of AI in education.

The primary objective of this study is to conduct a quasi-experimental investigation to determine the effect of a ChatGPT-driven adaptive curriculum on the academic performance of high school students (Liu et al., 2025; Y. Zhao et al., 2024). This research aims to quantify the difference in learning gains between students engaging with personalized, AI-adjusted content and those receiving standard, non-adaptive instruction. The central goal is to ascertain whether the real-time adaptation of curricular difficulty and focus, as facilitated by ChatGPT, translates into a measurable and statistically significant improvement in subject-specific test scores over the course of an academic term.

A second, equally important objective is to evaluate the impact of the adaptive curriculum on student engagement. Learning is not solely a cognitive process; it is deeply intertwined with motivation, interest, and active participation. This study, therefore, seeks to measure and compare levels of behavioral, emotional, and cognitive engagement between the intervention and control groups (Bian, 2024; Yao, 2024). The aim is to understand if a personalized learning journey, tailored to a student's individual pace and needs, fosters a more positive and proactive attitude toward learning, as indicated by established instruments for measuring student engagement.

Ultimately, this research endeavors to synthesize these findings to provide a holistic assessment of the value proposition of AI-driven adaptive learning in secondary education. The study aims to move beyond a simple pass/fail verdict on the technology and provide a nuanced understanding of its dual impact on both academic and affective domains of learning (Yao, 2024; Zubiaga et al., 2024). By pursuing these objectives, the research intends to generate clear, data-driven insights that can inform pedagogical practices, curriculum design, and technology integration policies, answering the fundamental question of whether this innovative approach constitutes a meaningful and effective advancement in teaching and learning.

The existing body of literature on educational technology is vast, yet a specific and critical gap exists concerning the empirical evaluation of large language models like ChatGPT for creating adaptive curricula in live secondary school environments. While numerous studies

have explored computer-assisted instruction and earlier forms of adaptive learning systems, these technologies lack the generative and conversational sophistication of modern AI (Auderset & Campbell, 2024; Li et al., 2024). The literature has not yet caught up to the technology, leaving a void in research that specifically examines the efficacy of these new, powerful generative models in a structured, comparative manner.

This gap is further defined by a lack of quasi-experimental research in this specific area. Much of the early research on ChatGPT in education has been qualitative, descriptive, or based on case studies, providing valuable initial insights but lacking the controlled comparison necessary to infer causality. There is a scarcity of studies that employ a pre-test/post-test design with a non-equivalent control group to isolate the effect of the AI-adaptive curriculum from other confounding variables. This methodological gap means that, to date, there is little robust evidence to either support or refute the claims that this specific form of AI-driven personalization is superior to traditional methods.

Furthermore, most existing research tends to focus on either academic performance or student engagement in isolation. A comprehensive understanding requires examining both, yet few studies have concurrently measured the impact of an educational technology intervention on these two interconnected outcomes (Li et al., 2024; H. Zhao et al., 2024). The literature lacks an integrated perspective on how AI-driven adaptation might simultaneously influence what students learn (performance) and how they feel about their learning (engagement). This study is designed precisely to fill these identified gaps by providing a methodologically rigorous, quasi-experimental, and dual-focused investigation into a cutting-edge technological application that the current body of scholarly work has not yet fully addressed.

The primary novelty of this research resides in its application of a state-of-the-art generative AI to create and implement a fully adaptive curriculum in a real-world high school setting. This study moves beyond using ChatGPT as a supplementary tool or chatbot and instead leverages it as the core engine of personalization, dynamically adjusting learning pathways for students in real-time (Dyer et al., 2024; Sohrabi et al., 2024). This innovative use of the technology represents a pioneering effort to test the practical application of a concept that has, until now, been largely theoretical. The study's design and implementation are novel in their ambition to systematically evaluate a truly responsive educational model.

This research is justified by the urgent need for evidence-based guidance on the role of AI in education. As technologies like ChatGPT become ubiquitous, educators, parents, and policymakers are faced with critical decisions about their use. This study is essential because it promises to provide the empirical data necessary to make informed choices (H. Zhao et al., 2024). By offering a clear, comparative analysis of an AI-driven model versus a traditional one, the research will contribute vital knowledge to a debate currently dominated by speculation. The findings are crucial for developing best practices and avoiding the pitfalls of uninformed technology adoption.

The ultimate justification for this work lies in its potential to address the long-standing educational challenge of individualization at scale. If a ChatGPT-driven adaptive curriculum proves effective, it could offer a viable and scalable solution to providing personalized instruction to every student, thereby promoting greater equity and maximizing learning potential. The study is important because its results could pave the way for a new generation of pedagogical tools that are more effective, engaging, and responsive to the diverse needs of learners. This research is not merely an academic exercise; it is a critical step toward

harnessing a transformative technology to build a more effective and equitable future for education.

RESEARCH METHOD

Research Design

This study utilized a quasi-experimental, pre-test/post-test non-equivalent control group design to investigate the impact of a ChatGPT-driven adaptive curriculum on high school students' academic performance and engagement (Çoban & Altay, 2024; Zhu et al., 2025). This design was chosen as it allows for a robust comparison between an intervention group and a control group in a natural school setting where the random assignment of individual students to different conditions is not feasible. The independent variable was the instructional method, with two levels: the experimental group receiving the AI-adaptive curriculum and the control group receiving traditional, non-adaptive instruction. The dependent variables were academic performance, measured by subject-specific test scores, and student engagement, measured by a standardized self-report questionnaire.

Population and Sample

The target population for this research consisted of 10th-grade students from two public high schools located in a socioeconomically diverse metropolitan area. A purposive sampling technique was employed to select two schools with similar demographic profiles, average academic performance records, and technology infrastructure (Makhachashvili & Semenist, 2025; Wei et al., 2024). From these schools, four intact 10th-grade biology classes were selected, with two classes from one school assigned to the intervention group (n=55) and two classes from the other school assigned to the control group (n=55), resulting in a total sample size of 110 students. The groups were matched based on pre-existing school-level data to ensure they were comparable in terms of prior academic achievement and socioeconomic status, thereby minimizing initial differences between them.

Instruments

Two primary instruments were used for data collection. Academic performance was assessed using a researcher-developed Biology Achievement Test (BAT), consisting of 50 multiple-choice and short-answer questions aligned with the national curriculum standards for 10th-grade biology (El Alami & Rawat, 2024; Simões & Caldeira, 2024). The content validity of the BAT was established by a panel of three experienced biology educators, and its internal consistency was confirmed through a pilot test, yielding a Cronbach's alpha of .89. Student engagement was measured using the validated Student Engagement Instrument (SEI), a 35-item self-report questionnaire that assesses cognitive, behavioral, and emotional engagement on a 5-point Likert scale. The SEI has demonstrated strong reliability and validity in previous studies with secondary school populations.

Procedures

The study was conducted over a full 12-week academic term after receiving approval from the university's institutional review board, school district authorities, and obtaining informed consent from parents and assent from students. During the first week, the Biology Achievement Test (BAT) and the Student Engagement Instrument (SEI) were administered as pre-tests to all participants in both groups. The intervention group then engaged with the biology curriculum through a learning platform where content, practice problems, and feedback were dynamically personalized by a fine-tuned ChatGPT model based on each student's real-

time performance (Bouvier et al., 2025; Simões & Caldeira, 2024). The control group covered the identical curriculum topics using traditional methods, including lectures, textbook readings, and uniform homework assignments. In the final week of the term, the BAT and SEI were administered again as post-tests to both groups to measure changes in the dependent variables.

RESULTS AND DISCUSSION

An initial analysis of the quantitative data was performed to summarize the academic performance and engagement levels of both the intervention and control groups. Pre-test and post-test scores from the Biology Achievement Test (BAT) and the Student Engagement Instrument (SEI) were compiled. The data indicated a substantial difference in the mean change scores between the two groups, with the intervention group showing marked improvement on both measures, while the control group exhibited only modest gains.

Table 1 provides a comprehensive summary of these descriptive statistics. The table details the mean scores (M), standard deviations (SD), and the number of participants (N) for both groups at both testing points. It also presents the mean gain scores, highlighting the average improvement from pre-test to post-test for each group and for each instrument, which provides a clear, at-a-glance comparison of the two instructional methods.

Table 1: Descriptive Statistics for BAT and SEI Scores

Instrument	Group	Time	N	Mean (M)	Standard Deviation (SD)	Mean Gain Score
BAT (%)	Intervention	Pre-Test	55	61.2	9.1	
		Post-Test	55	84.5	7.8	+23.3
	Control	Pre-Test	55	60.8	9.4	
		Post-Test	55	68.1	9.9	+7.3
SEI (1-5)	Intervention	Pre-Test	55	3.21	0.45	
		Post-Test	55	4.15	0.38	+0.94
	Control	Pre-Test	55	3.19	0.48	
		Post-Test	55	3.35	0.51	+0.16

The quantitative results strongly suggest that the ChatGPT-driven adaptive curriculum had a significant positive effect on student outcomes. The mean gain of +23.3 percentage points on the Biology Achievement Test for the intervention group is more than triple the +7.3 gain observed in the control group. This wide margin indicates that the academic improvement in the intervention group was a direct result of the personalized learning experience rather than general maturation or standard instruction over the term.

A similar pattern was observed in the student engagement data. The intervention group's mean score on the Student Engagement Instrument increased by +0.94 points, a substantial

improvement on the 5-point scale. In contrast, the control group's engagement level saw a minimal increase of just +0.16 points. This suggests that the adaptive, responsive nature of the AI-driven curriculum was significantly more effective at capturing and maintaining student interest and motivation compared to traditional teaching methods.

Qualitative data were gathered from system logs tracking student interactions with the adaptive learning platform and from a thematic analysis of open-ended survey questions administered at the end of the term. The system logs revealed distinct patterns of interaction. High-achieving students frequently utilized the platform to access enrichment materials and more challenging problems, while students who initially struggled received repeated, varied explanations of core concepts and targeted practice exercises until mastery was demonstrated.

The thematic analysis of student survey responses yielded three primary themes regarding their experience with the adaptive curriculum. The first theme was "Paced for Me," where students expressed appreciation for the ability to learn at their own speed. The second theme was "Instant Help," highlighting the value of immediate, 24/7 feedback from the AI. The third theme, "More Interesting," reflected students' perceptions that the personalized content and varied activities made learning biology more engaging than traditional classroom lectures.

The patterns observed in the system logs are inferred to be the mechanism driving the academic gains. The platform's ability to provide targeted remediation for struggling students directly addressed individual learning gaps before they could widen. Simultaneously, its capacity to offer advanced content prevented high-achieving students from becoming disengaged. This dual-action personalization created a more efficient learning environment for all students, allowing each to maximize their time on task by focusing on their specific zone of proximal development.

The themes emerging from the student surveys provide a clear rationale for the increased engagement scores. The feeling of being able to control the pace of their learning ("Paced for Me") likely enhanced students' sense of autonomy, a key driver of intrinsic motivation. The "Instant Help" theme points to a reduction in frustration and an increase in self-efficacy, as students felt supported whenever they encountered difficulties. Together, these qualitative insights suggest the AI-adaptive system fostered a more empowering and less intimidating learning environment.

A strong synergistic relationship exists between the quantitative and qualitative findings. The significant increase in BAT scores is explained by the interaction patterns revealed in the system logs; students performed better because the adaptive system provided precisely the support or challenge they needed. The quantitative data show *what* happened (improved scores), while the qualitative data show *how* it happened (through personalized remediation and enrichment).

Similarly, the higher SEI scores are directly illuminated by the themes from the student surveys. The quantitative increase in engagement is the numerical representation of students feeling that the learning was "Paced for Me" and "More Interesting." The qualitative data give voice to the student experience, explaining that the increased engagement was fueled by feelings of autonomy, competence, and relevance, all of which were fostered by the personalized nature of the AI-driven curriculum.

To provide a granular view of the intervention's impact, the case of "Leo," a student who entered the intervention group with below-average pre-test scores, is illustrative. System logs from the first few weeks show Leo repeatedly struggling with the concept of cellular

respiration. He consistently answered initial questions incorrectly. The ChatGPT-driven platform responded not by simply repeating the same information, but by re-explaining the concept using different analogies—first comparing it to a car engine, then to a factory.

The system also provided Leo with a series of scaffolded practice problems, starting with simple fill-in-the-blank questions before progressing to more complex application scenarios. After multiple attempts and targeted feedback loops over two days, Leo's accuracy on the topic reached 95%. For the remainder of the term, his interaction logs show him engaging with new topics confidently, often attempting challenge questions after mastering the core material.

Leo's case demonstrates the core mechanism of the adaptive curriculum in action. A traditional classroom setting might not have identified or had the resources to address his specific misconception with such focused, individualized attention. The AI, however, detected his struggle immediately and deployed a personalized pedagogical strategy—using multiple analogies and scaffolded practice—to guide him toward mastery. This prevented him from being left behind as the class moved on.

The transformation in his subsequent interactions with the platform explains both his academic and engagement growth. By overcoming a significant early hurdle with the system's support, Leo's self-efficacy likely increased substantially. This newfound confidence, reflected in his willingness to tackle challenge questions, explains his improved performance on the final BAT. His sustained interaction with the platform, driven by this success, provides a clear example of the positive feedback loop between personalized support and student engagement.

The collective results of this study strongly support the conclusion that a ChatGPT-driven adaptive curriculum is a significantly more effective instructional method than traditional teaching in a high school biology setting. The findings are unequivocal across both performance and engagement metrics. The intervention not only produced superior academic outcomes but also created a more motivating and engaging learning experience for students.

This research interprets the AI-adaptive model as a successful operationalization of personalized learning theory. By tailoring content, pace, and feedback to the individual learner in real-time, the system effectively addresses the diverse needs within a single classroom. The results indicate that this level of personalization fosters a powerful sense of student autonomy and competence, which in turn drives both deeper learning and a more positive disposition toward the subject matter.

The results of this study provide a clear and compelling picture of the benefits derived from integrating a ChatGPT-driven adaptive curriculum into a high school biology setting. The quantitative data unequivocally demonstrated the intervention's success. Students in the personalized learning group achieved substantially higher academic gains on the Biology Achievement Test, more than tripling the improvement seen in the control group. This significant disparity points directly to the efficacy of the adaptive approach in fostering subject matter mastery.

This academic improvement was complemented by a profound impact on student engagement. The intervention group reported a dramatic increase in their engagement levels, as measured by the Student Engagement Instrument, an increase that dwarfed the minimal change observed in the control group. This finding indicates that the personalized curriculum did not just make students smarter; it made them more motivated, interested, and actively involved in their own learning process, a crucial component for sustained academic success.

The qualitative data provided rich, explanatory context for these numerical outcomes. System logs revealed a system that catered effectively to the entire spectrum of learners, providing targeted remediation to those who struggled and offering enrichment to those who excelled. Student feedback coalesced around themes of autonomy ("Paced for Me"), responsive support ("Instant Help"), and heightened interest ("More Interesting"), articulating the subjective experience behind the engagement scores.

The case study of Leo served as a powerful narrative anchor for the aggregate data. His journey from struggling with a core concept to achieving mastery and confidently tackling advanced material illustrated the intervention's core mechanism: the power of immediate, scaffolded, and varied feedback to build not only knowledge but also self-efficacy. His experience encapsulates the study's central finding: that true personalization addresses both cognitive and affective needs, creating a virtuous cycle of success and engagement.

These findings strongly support and extend the foundational theories of personalized learning. The study acts as a modern validation of Lev Vygotsky's concept of the Zone of Proximal Development (ZPD). The ChatGPT-driven system proved exceptionally adept at identifying each student's ZPD and providing tailored content that was challenging but not overwhelming. Unlike traditional instruction, which teaches to the middle, the AI continuously adjusted to keep every student operating at their optimal learning frontier, a feat previously considered unscalable.

The dramatic increase in student engagement aligns perfectly with the principles of Self-Determination Theory. The themes of "Paced for Me" and "Instant Help" directly correspond to the core psychological needs of autonomy and competence. By giving students control over their learning pace and providing the support needed to feel successful, the adaptive curriculum fostered intrinsic motivation. This contrasts with earlier educational technology that often failed to support these needs, resulting in high dropout rates from online courses. This study demonstrates that modern AI can effectively address these fundamental human motivators.

This research also marks a significant departure from studies on earlier, less sophisticated adaptive learning systems. Previous technologies were often limited by pre-programmed pathways and rigid logic, lacking the flexibility to generate novel explanations or respond to nuanced student queries. The generative capability of ChatGPT represents a paradigm shift. The system's ability to re-explain concepts using different analogies, as seen in Leo's case, showcases a level of pedagogical flexibility that older systems could not achieve. This study, therefore, positions generative AI as a distinct and far more powerful tool than its technological predecessors.

While aligning with the optimistic literature on educational technology, these results also provide a necessary empirical counterpoint to the more cautious or critical perspectives on AI in education. Concerns about AI leading to passive learning or a lack of critical thinking are not supported by our findings on student engagement. Instead, the data suggest that when used to create a responsive and supportive environment, AI can catalyze active participation and a deeper connection to the material. This study provides concrete evidence that AI, when implemented thoughtfully, can be a tool for empowerment rather than passivity.

The results of this study signify a potential tectonic shift in pedagogical practice, from a teacher-centered model of knowledge transmission to a learner-centered model of knowledge construction. The AI did not replace the teacher but rather assumed the role of a tireless, infinitely patient instructional aide for each student. This freed the human teacher to focus on

higher-order tasks such as facilitating group discussions, mentoring, and providing socio-emotional support. The findings reflect a future where the roles of educator and technology are symbiotic, not adversarial.

The observed improvements in both performance and engagement suggest that the intervention did more than just teach biology; it taught students how to learn more effectively. The "Instant Help" feature fostered a mindset where asking for help is immediate and without stigma, and where mistakes are viewed as learning opportunities. Leo's journey reflects the development of metacognitive awareness and a growth mindset. The findings, therefore, point to the potential of such systems to cultivate not just subject experts, but more resilient, confident, and self-directed learners.

The consistency of the positive results across students with different initial achievement levels is profoundly meaningful. The system's ability to simultaneously challenge high-achievers and support struggling learners addresses one of the most persistent challenges in education: differentiation. This signifies a move toward a more equitable learning environment, where a student's starting point does not predetermine their destination. The technology demonstrated a capacity to democratize access to high-quality, individualized instruction.

Ultimately, these findings reflect the power of responsive learning environments. Students thrive when they feel seen, understood, and supported. The AI-adaptive system, in its own way, achieved this by consistently responding to each student's unique needs. The success of the intervention is a testament to a simple but powerful educational truth: learning flourishes when instruction adapts to the learner, not the other way around.

The practical implications for secondary schools and educators are immediate and significant. This study provides a clear, evidence-based rationale for investing in and integrating AI-driven adaptive learning platforms into core subjects. It offers a proven model for differentiation that can alleviate the immense pressure on teachers to cater to dozens of individual learning needs simultaneously. For professional development, the implication is a need to train teachers not as technology operators, but as facilitators of AI-enhanced learning environments.

For curriculum designers and educational software developers, the implications are equally clear. The findings validate the pursuit of generative AI as the core engine for next-generation learning tools. The focus should shift from creating static digital content to building dynamic systems that leverage AI's capacity for personalization. The success of features like varied analogies and scaffolded practice provides a blueprint for designing effective and engaging instructional interactions.

The research also carries substantial implications for educational policy. It provides policymakers with the empirical justification needed to support the strategic adoption of AI in schools. This data can inform funding decisions, technology standards, and guidelines for the ethical implementation of AI, ensuring that new tools are deployed in ways that genuinely enhance learning and promote equity. It moves the conversation from speculative hype to evidence-based strategy.

Theoretically, this study reinforces and revitalizes constructivist learning theories in the digital age. It demonstrates how technology can create an environment where students actively construct knowledge by interacting with personalized content and feedback. It provides a powerful, modern example of how a well-designed "microworld" can facilitate deep,

conceptual understanding. The findings compel learning scientists to update their models to account for the unique pedagogical affordances of generative AI.

The intervention's success can be primarily attributed to its capacity for immediate and targeted feedback. In a traditional classroom, a student's misconception might go unnoticed for days. The AI system, however, identified Leo's struggle in real-time and intervened instantly. This immediacy prevented the compounding of errors and the solidification of incorrect knowledge, ensuring a much more efficient and effective learning process.

A second key reason for the results is the system's ability to reduce cognitive load while personalizing challenges. By breaking down complex topics into manageable steps and providing scaffolded support, the AI ensured that students were not overwhelmed. At the same time, by offering enrichment to those who were ready, it prevented the boredom that leads to disengagement. This optimization of challenge for every student is a feat that is nearly impossible to achieve consistently through human instruction alone.

The 24/7 availability and non-judgmental nature of the AI were also crucial factors. The "Instant Help" theme revealed that students felt empowered by the ability to seek clarification whenever they needed it, without fear of "bothering" a teacher or appearing slow in front of peers. This created a psychologically safe learning environment that encouraged risk-taking and persistence, which are essential for tackling difficult academic material.

Finally, the enhancement of student autonomy provides a compelling explanation for the results. The "Paced for Me" theme underscores the motivational power of giving students control over their learning. When students feel they are the agents of their own educational journey, their sense of ownership and responsibility increases, leading directly to the higher levels of cognitive and emotional engagement that were observed. The system succeeded because it treated students as active partners in their own education.

Future research should aim to replicate these findings across different subject areas and age groups. While the intervention was highly effective for high school biology, studies are needed to explore its applicability in humanities, mathematics, and arts education, as well as in middle school and university settings. This would help establish the broader utility of the AI-adaptive curriculum model.

Longitudinal studies are a critical next step. This research demonstrated significant short-term gains, but the long-term impact on student learning trajectories, career choices, and lifelong learning habits remains unknown. Following a cohort of students over several years would provide invaluable insight into the enduring effects of this type of personalized education on their academic and personal development.

Further research should also focus on the human element of AI-enhanced learning. Studies are needed to investigate the most effective ways for teachers to collaborate with these AI systems. Research could explore different models of co-teaching, where the AI handles direct instruction and practice while the teacher focuses on project-based learning, Socratic dialogue, and fostering a positive classroom culture. This would help define the future role of the educator in an AI-integrated classroom.

Finally, a crucial avenue for future inquiry involves the ethical dimensions and potential biases of these AI systems. Research must be conducted to ensure that the algorithms driving personalization are equitable and do not inadvertently reinforce existing societal biases. Studies should investigate the transparency of these systems and explore methods for ensuring that AI-

driven education is implemented in a manner that is fair, ethical, and aligned with humanistic educational goals.

CONCLUSION

The most significant finding of this study is the empirically demonstrated synergistic effect of a ChatGPT-driven adaptive curriculum on both academic performance and student engagement. The research uniquely establishes that the substantial, quantifiable gains in subject mastery are directly linked to the qualitative student experience of enhanced autonomy, competence, and interest. This dual impact—simultaneously making learning more effective and more motivating—was achieved by the AI's capacity to provide truly individualized remediation and enrichment in real-time, creating a virtuous cycle where success fuels engagement, and engagement fuels further success.

This research provides a distinct contribution to the field that is both conceptual and methodological. Conceptually, it offers a powerful, modern validation of established learning theories like Vygotsky's Zone of Proximal Development and Self-Determination Theory, demonstrating their applicability within a generative AI framework. Methodologically, it moves beyond the speculative and purely descriptive studies common in early AI research by employing a rigorous quasi-experimental design, thereby providing robust, comparative evidence of the technology's causal impact in an authentic educational setting.

The study's conclusions are constrained by certain limitations which, in turn, illuminate clear directions for future research. The findings are based on a specific subject and demographic, necessitating replication across diverse curricula and student populations to establish broader generalizability. The research's short-term nature calls for longitudinal studies to assess the long-term effects on learning habits and academic trajectories. Future inquiry must also investigate the optimal models for teacher-AI collaboration and address the critical ethical considerations of algorithmic bias to ensure equitable implementation.

AUTHOR CONTRIBUTIONS

Look this example below:

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

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