

THE IMPACT OF DATA-DRIVEN PERSONALIZED LEARNING PATHWAYS ON THE ACADEMIC AND SKILLS PERFORMANCE OF VOCATIONAL COLLEGE STUDENTS IN CHINA: THE MEDIATING ROLE OF LEARNING ENGAGEMENT AND THE MODERATING EFFECT OF CAREER ASPIRATION

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Abstract: This study investigates the impact of data-driven personalized learning paths on the academic and skill performance of vocational college students in China, with a focus on the mediating role of learning engagement and the moderating effect of career aspirations. Based on self-determination theory, learning engagement theory, and career construction theory, an integrated structural model was constructed to reveal how personalized teaching strategies and institutional support influence student learning outcomes through learning behavior mechanisms. The following hypotheses are proposed: H1: Data-driven personalized learning paths have a significant positive impact on student performance. H2: Institutional support has a significant positive impact on student performance. H3: Learning engagement mediates the relationship between personalized learning paths and student performance. H4: Career aspirations moderate the relationship between learning engagement and student performance, such that when students have higher career aspirations, the impact of learning engagement on performance is more significant.

A cross-sectional survey was conducted among 475 students from multiple vocational colleges across China. Validated Likert-scale instruments were used to measure key variables, including personalized learning, institutional support, learning engagement, career aspiration, and student performance. The data were analyzed using structural equation modeling, along with mediation and moderation testing via bootstrapping techniques.

The findings reveal that both personalized learning pathways and institutional support significantly predict students' academic and skills performance. Learning engagement serves as a partial mediator in the relationship between personalized learning and student outcomes, suggesting

that increased engagement is a crucial mechanism through which personalization enhances performance. Moreover, career aspiration negatively moderates the relationship between learning engagement and student performance, indicating that the strength of this link is slightly weaker among students with higher career ambition.

This research contributes theoretically by integrating multiple psychological and educational frameworks to explain learning outcomes in vocational contexts. Practically, it offers valuable insights for educational institutions, instructors, and policymakers to optimize personalized learning systems, enhance learner engagement, and provide targeted support based on students' career motivation levels. The study also highlights the need for data-driven teaching reforms to ensure equitable, responsive, and future-oriented vocational education.

Keywords: Personalized Learning, Learning Engagement, Career Aspiration, Student Performance

Introduction

In the context of China's socio-economic transformation and the rising demand for high-quality technical and skilled personnel, the vocational education system has taken on an increasingly critical role in national talent development. With strategic goals such as intelligent manufacturing, industrial digitization, and green development driving the evolution of the workforce, vocational education is no longer seen as merely supplementary to general education, but rather as an equally vital pathway toward practical and industry-aligned learning outcomes.

Despite notable advancements in infrastructure, policy support, and enrollment expansion, China's vocational education still faces several deeply rooted challenges. These include, but are not limited to, the persistent social undervaluation of vocational tracks, insufficiently flexible curricula, a gap between training outcomes and labor market demands, and significant disparities in the distribution of high-quality educational resources. Most importantly, traditional teaching models in vocational institutions often adopt standardized instructional designs, failing to adequately respond to the diverse needs, capabilities, learning preferences, and career goals of individual students.

At the same time, the emergence of intelligent education technologies has opened new possibilities for addressing the heterogeneity of learners. In particular, the rise of data-driven personalized learning pathways, empowered by educational big data, learning analytics, and artificial intelligence-based recommendation systems, is transforming the way teaching is designed, delivered, and adapted. These systems are capable of continuously collecting, analyzing, and interpreting learners' behavioral, emotional, and performance-related data in real time. Based on these dynamic profiles, educational content, pacing, delivery mode, and assessment mechanisms can be customized to better meet individual needs.

In vocational education contexts, this form of personalized learning has particularly strong

relevance. Vocational students often vary in terms of academic foundation, skill acquisition rate, and occupational direction. A standardized curriculum may result in disengagement, frustration, or underperformance. Personalized learning, by contrast, offers differentiated pathways, allowing students to progress at their own pace, follow targeted modules that align with their career interests, and receive timely feedback tailored to their learning behaviors and performance indicators. However, while the technology may be available, the actual psychological mechanism and learning effectiveness of personalized learning in vocational education remain underexplored, especially in the Chinese context.

The current study thus arises from the need to bridge this empirical and practical gap. By exploring how data-driven personalized learning pathways influence student outcomes in vocational colleges in China, this research aims to contribute not only to the academic understanding of personalized learning, but also to practical reforms in vocational instruction and institutional support systems. The study is grounded in three theoretical frameworks: Self-Determination Theory, which emphasizes the importance of learner autonomy, competence, and relatedness in driving motivation and engagement; Learning Engagement Theory, which views engagement as a dynamic interaction of emotional, behavioral, and cognitive dimensions; and Career Construction Theory, which highlights the role of career clarity, vocational identity, and personal agency in shaping educational choices and learning effort.

In this conceptual framework, personalized learning pathways are posited to have both direct and indirect effects on students' academic and skills performance. The indirect effect is proposed to be mediated by learning engagement, reflecting the hypothesis that students who are provided with adaptive, personalized, and responsive learning environments are more likely to engage deeply with the learning process—cognitively, emotionally, and behaviorally—thus improving their learning outcomes. Furthermore, the research introduces career aspiration as a moderator variable, under the assumption that students with higher levels of career clarity and ambition may respond differently to engagement strategies compared to those with lower vocational self-concept. This introduces an important individual difference dimension to the model and allows for a more nuanced analysis of personalization effectiveness.

It is also important to note the broader educational policy environment within which this study is situated. China's Ministry of Education has placed increasing emphasis on “smart education” and “individualized learning,” calling for the integration of advanced technology into teaching practices and institutional management. The "National Vocational Education Reform Implementation Plan" explicitly encourages the development of intelligent learning platforms, the use of data to improve teaching quality, and the alignment of vocational training with future employment and industrial transformation. However, while these policy visions are ambitious, there remains a significant gap between theoretical policy frameworks and the actual implementation of personalized education in everyday classrooms. Teachers may lack the training to interpret learning analytics; students may lack digital literacy;

institutions may not yet have the infrastructure to scale personalized systems effectively.

Thus, this study is timely and necessary. By anchoring its research model in well-established psychological theories, targeting a population of learners often marginalized in educational research, and focusing on a novel educational technology intervention, the study provides valuable insights into how personalized learning operates at both the psychological and institutional level in vocational education. It moves beyond descriptive claims about “what works” to examine “how” and “for whom” it works, which is critical for the next phase of educational transformation.

In sum, this research takes place at the convergence of four pressing demands: (1) the national imperative for skilled labor aligned with future industries, (2) the technological opportunity to personalize learning at scale, (3) the psychological need to understand engagement and motivation mechanisms among vocational learners, and (4) the institutional challenge of making personalized learning equitable, effective, and sustainable. By exploring the interactions among personalized learning, institutional support, learning engagement, and career aspiration, this study contributes to a richer and more actionable understanding of how data-driven educational innovation can enhance vocational education in China and beyond.

Research Objectives

The central aim of this study is to construct and empirically validate an integrated theoretical model to examine how data-driven personalized learning pathways influence the academic and skills performance of vocational college students in China. With the rapid advancement of educational informatization, personalized learning technologies have become increasingly essential in addressing the diversified and individualized learning needs in vocational education. However, there remains a lack of systematic inquiry into how such technologies function in practice, particularly in terms of their psychological mechanisms and boundary conditions. Therefore, this study endeavors to investigate not only the direct influence of data-driven personalized learning pathways on student outcomes but also the mediating role of learning engagement and the moderating effect of career aspiration in this process.

To address this overarching research goal, the study outlines five specific objectives that approach the research questions from four key dimensions: direct effects, mediation mechanisms, moderation effects, and integrated structural modeling.

1. To evaluate the direct effects of data-driven personalized learning pathways on student performance.

This objective aims to examine whether data-driven personalized learning pathways directly enhance students' learning outcomes, including academic achievement (e.g., examination results, academic self-efficacy), skills acquisition (e.g., operational proficiency, problem-solving abilities), and career readiness (e.g., professional awareness, resume preparation, interview skills). Grounded in Self-Determination Theory, it is hypothesized that when students are provided with personalized content,

self-paced progression, and responsive feedback, they are more likely to experience higher levels of intrinsic motivation, which contributes to improved learning performance. Hence, assessing the direct impact of personalized learning pathways provides a foundational understanding of their effectiveness in real educational contexts.

2. To analyze the direct effects of institutional support on student performance.

The successful implementation of personalized learning cannot rely solely on technological tools; it requires robust institutional support to ensure sustainability and effectiveness. This objective focuses on evaluating the role of institutional support—including digital infrastructure (e.g., learning platforms, smart classrooms), teacher facilitation (e.g., guidance strategies, response mechanisms), and access to learning resources (e.g., material richness, ease of access)—in shaping student outcomes. The hypothesis is that strong institutional support serves as an enabling environment that enhances student experiences, learning participation, and ultimately, performance. This analysis will help determine whether the institutional context significantly amplifies or constrains the effectiveness of personalized learning strategies.

3. To explore the mediating role of learning engagement in the relationship between personalized learning pathways and student performance.

Learning engagement is widely regarded as the psychological and behavioral bridge between instructional design and student success. This objective aims to test whether learning engagement serves as a mediating variable between personalized learning pathways and learning outcomes. Learning engagement comprises behavioral (e.g., attention, participation), emotional (e.g., interest, belongingness), and cognitive (e.g., self-regulation, strategic thinking) dimensions. Based on Learning Engagement Theory, it is anticipated that personalized learning environments foster deeper engagement by enhancing relevance, autonomy, and feedback responsiveness. Verifying this mediation mechanism will reveal the underlying process through which personalized learning exerts its influence, thereby enriching our understanding of why such strategies are effective.

4. To analyze whether career aspiration moderates the relationship between learning engagement and student performance.

Individual differences among learners are known to significantly influence how instructional interventions affect learning outcomes. Career aspiration is conceptualized as a future-oriented motivational factor reflecting the clarity, value, and feasibility of a student's vocational goals. According to Social Cognitive Career Theory, students with stronger career aspirations tend to exhibit greater self-efficacy, goal commitment, and persistence in learning. This objective examines whether the effect of learning engagement on performance is conditioned by students' levels of career aspiration. Specifically, it seeks to determine whether engagement yields stronger performance outcomes among students with higher vocational clarity and drive. Identifying this moderating relationship will provide insight into "for whom" personalized learning is most effective and will offer guidance for differentiated

instructional support.

5. To construct and validate a structural equation model illustrating the combined influence of personalized learning pathways, institutional support, learning engagement, and career aspiration on student performance.

Building upon the previous four objectives, this final goal involves developing a comprehensive structural equation model that maps the complex relationships among the key constructs in this study. The model will capture the direct pathways, the mediating role of learning engagement, and the moderating effect of career aspiration in a unified framework. It will allow for comparison of the relative strengths of each path and offer a holistic understanding of how pedagogical design, environmental conditions, psychological engagement, and individual aspirations collectively shape student learning outcomes. Furthermore, the validated model can serve as a reference for policy makers, educators, and system designers in implementing effective personalized learning interventions in vocational education.

In summary, these five research objectives are distinct yet interrelated, forming a coherent framework that moves from identifying the presence of effects to explaining mechanisms and specifying boundary conditions. They reflect a full chain of inquiry from “whether personalized learning works,” to “how it works,” to “for whom it works best,” and “how it can be optimized.” This comprehensive approach not only responds to the practical challenges of implementing personalized learning in Chinese vocational education but also contributes to theoretical advancements in the fields of learning science, educational psychology, and instructional technology.

Literature Review

As the digital transformation of education deepens, personalized learning has emerged as a central focus in contemporary educational reform. In contrast to traditional “one-size-fits-all” models characterized by uniform pacing and content, personalized learning emphasizes learner-centered instruction tailored to individual differences in students’ abilities, interests, learning styles, and career goals. In this context, data-driven personalized learning pathways (DDPLPs) have attracted increasing attention from researchers and practitioners in vocational education. Particularly within the highly heterogeneous environment of vocational institutions—where student profiles vary significantly in background and future trajectories—DDPLPs are viewed as a powerful tool for improving instructional efficiency, enhancing engagement, and optimizing skill development outcomes.

The study of personalized learning can be traced back to the 1970s, initially focused on differentiated teaching practices guided by instructors. Over time, it has evolved toward technology-supported adaptive learning. With the emergence of learning analytics, artificial intelligence-based recommendation engines, and large-scale data modeling, modern personalized learning systems can track learners’ behaviors in real time, construct precise learner profiles, and dynamically adjust instructional content according to learners’ cognitive levels, preferences, and behavioral patterns—

offering scalable “one-to-one” learning support (Pane et al., 2015; Walkington, 2013).

In vocational education settings, the adaptability of personalized learning is especially critical. Students in vocational colleges exhibit considerable differences in prior knowledge, learning pace, skill needs, and occupational aspirations. Uniform instruction often fails to accommodate these needs (Zhang & Wu, 2021). Duckett (2010) emphasizes that in vocational education, the primary value of personalized learning lies not just in improving academic performance, but in enhancing practical skill application and employability. Holmes et al. (2019) further demonstrate that data-driven platforms can optimize instructional strategies and task allocation through feedback mechanisms, thereby improving learning efficiency and boosting both learner motivation and satisfaction.

Scholars in China are also increasingly recognizing the potential of personalized learning in vocational education. Li Guang and Jiang Yingjie (2018) assert that personalized learning should be embedded into the design and assessment systems of intelligent teaching platforms in vocational institutions, making it a core mechanism for instructional improvement. Wang Qiang et al. (2021), through empirical studies, found that classes utilizing personalized learning pathways in smart learning environments outperformed traditional classes in student participation, course performance, and skills competition results.

However, most existing research on personalized learning focuses heavily on technological affordances and implementation strategies, with relatively less attention paid to the internal psychological mechanisms, such as learning engagement, that mediate its effectiveness. Moreover, the literature seldom addresses individual difference variables—such as career aspiration—that might moderate the success of personalized learning interventions.

Institutional support plays a vital external role in enabling the effective implementation of personalized learning. DDPLPs rely heavily on a robust institutional environment, including functional platforms, high-quality data, timely feedback, and resource alignment. Whether these technical and instructional affordances can be realized depends significantly on institutional factors such as resource allocation, faculty development, and curricular integration (Siemens & Long, 2011).

Zhao (2023) notes that although many institutions have invested in intelligent learning platforms, deficiencies in institutional mechanisms—such as lack of faculty training, incomplete curriculum restructuring, and delayed feedback—often result in underutilization or ineffective use. He proposes a tripartite framework of “technology–teacher–institution,” arguing that institutional support encompasses not only physical infrastructure but also operational mechanisms and organizational culture. Other studies support this view. Liu Fang (2021) found that the management’s capacity to coordinate resources directly influences faculty acceptance and implementation of personalized learning. Chen Jing (2020) highlights that without sustained professional development, even the most advanced learning platforms are unlikely to produce meaningful improvements in learner experience.

In summary, institutional support constitutes the foundational condition for the successful

implementation of DDPLPs, yet it remains underrepresented in current modeling and analysis frameworks in the personalized learning literature.

Learning engagement is widely recognized as a key mediating mechanism linking instructional design and student outcomes. Fredricks et al. (2004) categorized engagement into three components: behavioral (e.g., participation, attendance), emotional (e.g., interest, identification), and cognitive (e.g., strategy use, self-regulation). Kahu (2013) conceptualizes engagement as a dynamic process driven by student motivation, teaching strategies, and institutional contexts. She emphasizes that the design of instructional practices that foster emotional and cognitive engagement is critical to achieving effective learning outcomes.

DDPLPs typically enhance students' autonomy, feedback responsiveness, and content relevance, thereby stimulating learning interest and active participation, which in turn fosters deeper engagement (Schunk & Mullen, 2012). Redding (2014) argues that in a data-rich learning environment, students are more likely to feel in control of their learning process, thereby activating intrinsic motivation and enabling them to self-regulate their pace and strategy use. This process enhances cognitive depth and long-term learning persistence.

Although numerous studies confirm the mediating role of engagement in the relationship between personalized learning and learning outcomes, few have examined how this mechanism functions within vocational education settings—especially where learning outcomes are defined in terms of skill mastery and career preparedness. Further exploration is needed to clarify the mediating paths and the relative influence of each engagement dimension.

Career aspiration is a motivational and goal-oriented personality variable that reflects an individual's vision, expectation, and determination regarding future career development. According to Social Cognitive Career Theory (Lent, Brown, & Hackett, 2002), career aspiration is shaped by self-efficacy, outcome expectations, and career interests, and strongly influences the directionality and persistence of learning behaviors.

Savickas (2005), in Career Construction Theory, emphasizes that one's vision and identification with a future career role constitutes the core of educational meaning-making in the present. Empirical studies show that students with high career aspirations are more likely to proactively set learning goals, utilize deep learning strategies, and demonstrate greater resilience when facing learning challenges (Lopez-Bonilla et al., 2012). However, Schoon and Polek (2011) caution that for high-aspiration students, the marginal benefit of engagement on performance may decrease, as such students are already driven by strong internal motivations aligned with vocational identity. Thus, career aspiration may exert a complex moderating effect on the relationship between learning engagement and learning performance.

Currently, research in vocational education seldom incorporates career aspiration into models of personalized learning pathways, and little is known about how this variable may produce

heterogeneous effects across different student groups—representing an important theoretical extension addressed by this study.

Student performance remains the ultimate variable for evaluating instructional effectiveness. In the context of vocational education, this encompasses cognitive outcomes (academic achievement), skill-based outcomes (technical proficiency), and developmental outcomes (career readiness). Mourshed et al. (2013) argue that assessment systems based solely on scores or course completion fail to capture whether students are developing the workplace competencies and behaviors required by employers.

Scholars in China are broadening performance evaluation frameworks accordingly. Wang Wei and Zhang (2022) proposed a three-part model of academic achievement, operational skills, and soft vocational competencies. Gao et al. (2022) suggested incorporating indicators of employability—such as resume writing, self-presentation, and career planning—into learning outcomes to better reflect the employment-oriented goals of vocational education.

This study, therefore, defines student performance as a composite latent construct comprising academic achievement, skill acquisition, and career readiness. It aims to explore how this construct is shaped by data-driven personalized learning pathways, institutional support, learning engagement, and career aspiration within a unified structural framework.

Methodology

This study employs a theory-guided, quantitatively driven approach to explore how data-driven personalized learning pathways (DDPLPs) influence the academic and skills performance of students in Chinese vocational colleges. Framed by Self-Determination Theory, Engagement Theory, and Social Cognitive Career Theory, the research further investigates the mediating role of learning engagement and the moderating effect of career aspiration. In order to provide empirical support for these hypothesized relationships, the study integrates a cross-sectional survey design, extensive scale development procedures, and advanced data analysis techniques.

Given the research aim of testing specific causal relationships between latent psychological and institutional variables, a quantitative methodology was deemed most appropriate. This approach allows for the systematic collection and statistical analysis of numerical data to uncover patterns and validate the proposed structural model. The data were collected through a structured questionnaire, distributed to a representative sample of vocational students across multiple Chinese provinces. The cross-sectional nature of the survey facilitated efficient access to a large and diverse respondent pool within a defined timeframe, thereby capturing a comprehensive snapshot of student experiences with personalized learning environments.

The research subjects were students enrolled in various types of vocational colleges in China. Due to the distinct characteristics of vocational education, which is practice-oriented and employment-

oriented, students exhibit significant heterogeneity in terms of learning ability, motivation, regional background, and development plans. Therefore, this group is more dependent on personalized support in the design of learning paths, making it highly realistic and representative for conducting this study.

To ensure broad representativeness and internal diversity, the study adopted a stratified random sampling strategy. The initial strata were formed according to the students' disciplinary tracks, such as engineering, business, education, and service industries. Within each track, further stratification was conducted by academic year, ranging from freshman to junior level. Random samples were then proportionally selected from each stratum. This multi-layered stratification ensured that the data captured a wide array of learner experiences while reducing the risk of sampling bias. The final sample was drawn from more than ten institutions located in both developed and developing regions, and questionnaires were administered either online or in person, depending on the institution's technical infrastructure. This dual distribution approach increased response rates and mitigated digital access inequalities.

Regarding sample size, the study initially set a minimum threshold of 400 valid responses, based on the widely accepted ratio of 10 participants per estimated parameter in structural equation modeling. Considering the complexity of the proposed model—which involves approximately 40 free parameters, including latent and observed variables—the research team implemented an over-distribution strategy, resulting in the collection of 475 valid responses after rigorous data cleaning. Several data quality assurance measures were applied, such as response time filtering, reverse-coded item validation, and pattern detection to eliminate inattentive or careless responses. These steps helped maintain the integrity of the dataset and ensured its suitability for subsequent statistical modeling.

Measurement instruments were carefully selected and refined from established scales to ensure validity and reliability. The finalized questionnaire included five sections: data-driven personalized learning pathways, institutional support, learning engagement, career aspiration, and academic and skills performance. All responses were captured using a 7-point Likert scale, with anchors ranging from 1 (strongly disagree) to 7 (strongly agree), allowing for precise quantification of latent constructs.

The personalized learning pathways scale was adapted from previous work by Jiang et al. (2022) and Tapalova and Zhiyenbayeva (2022). It measures three dimensions—content adaptation, learner autonomy, and personalized feedback—using ten items such as “The learning content adapts to my individual needs” and “I am able to choose learning paths that match my interests.” This scale captures the core functional elements of intelligent learning systems and their role in delivering adaptive learning experiences.

Institutional support was measured using an instrument based on the educational support perception framework developed by Zeng et al. (2024). This scale evaluates platform infrastructure, instructional facilitation, and accessibility of learning resources. Items include “Teachers offer individual support in navigating learning platforms” and “Digital learning materials are readily

available and accessible.” This construct reflects the environmental conditions that shape students’ access to, and experiences with, personalized learning.

Learning engagement was assessed through a revised version of the well-established multidimensional model by Fredricks et al. (2004). The scale includes behavioral items (e.g., attendance, effort), emotional items (e.g., enjoyment, belonging), and cognitive items (e.g., critical thinking, metacognitive strategies). Students rated items such as “I concentrate fully when studying” and “I use multiple strategies to improve my understanding.” This construct captures the motivational and participatory dimensions that mediate the influence of instructional design on performance outcomes.

Career aspiration was measured using a 9-item scale inspired by the principles of Career Construction Theory (Savickas, 2005). The items reflect goal clarity, career orientation, and future planning behaviors. Sample statements include “I have a clear vision of the profession I want to pursue” and “I actively seek opportunities that align with my career goals.” This construct is particularly relevant in the context of vocational education, where students’ perceptions of their future careers significantly influence their academic behaviors.

Finally, academic and skills performance was measured as a multidimensional outcome variable encompassing academic achievement, practical skill acquisition, and career readiness. The scale included ten items such as “I perform well in hands-on skill assessments” and “I feel confident in preparing for job interviews.” This outcome construct reflects the holistic goals of vocational education, encompassing both classroom learning and workplace preparation.

Before large-scale administration, a pilot study was conducted with 80 students from three institutions. This pilot phase helped ensure that all questionnaire items were clearly worded, culturally appropriate, and semantically unambiguous. It also allowed for preliminary assessments of reliability using Cronbach’s alpha and exploratory factor analysis. Items with low factor loadings or redundancy were revised or removed, and the scale was refined accordingly.

The full dataset was subjected to rigorous psychometric validation. An exploratory factor analysis using principal axis factoring and Promax rotation was first conducted to identify the underlying structure of each scale. This was followed by confirmatory factor analysis using the R lavaan package to test the measurement model. The model showed good fit according to standard indices: $\chi^2/df < 3.00$, Comparative Fit Index and Tucker–Lewis Index > 0.90 , and Root Mean Square Error of Approximation < 0.08 . Average variance extracted values for each construct exceeded 0.50, and standardized factor loadings were all above 0.60, confirming convergent validity. Discriminant validity was supported by comparing square roots of AVE with inter-construct correlations.

Reliability analysis was conducted using both Cronbach’s alpha and composite reliability. All constructs demonstrated excellent internal consistency, with Cronbach’s alpha values exceeding 0.80 and composite reliability values above 0.85. Inter-item correlations were within acceptable ranges, indicating that scale items were internally consistent while avoiding redundancy.

The data collection process followed strict ethical guidelines. Ethical clearance was obtained from the relevant academic institution. Participants were informed of the purpose of the study, the voluntary nature of their participation, and their right to withdraw at any time. Data were anonymized and securely stored. Personally, identifying information was neither collected nor inferred, ensuring full compliance with data protection and privacy norms.

Following data collection, responses were cleaned and screened for quality. Descriptive statistics were calculated to understand sample characteristics and distribution of key variables. The measurement model was tested through confirmatory factor analysis. Structural equation modeling was employed to examine the direct effects of personalized learning and institutional support on student performance, the mediating effect of learning engagement, and the moderating role of career aspiration.

Mediation effects were analyzed using bootstrapping with 5,000 resamples, allowing for robust estimation of indirect effects. The significance of mediation was determined based on bias-corrected confidence intervals. Moderation analysis was conducted by creating an interaction term between learning engagement and career aspiration, which was then tested within the structural model. The presence of moderation was established if the interaction term was statistically significant and improved model fit.

All analyses were conducted using R software and relevant packages, including tidyverse, lavaan, SemTools, and psych. These tools were chosen for their flexibility, transparency, and open-access nature, which align with the principles of reproducible research. Model interpretation was grounded in theoretical reasoning, and the magnitude, direction, and significance of estimated effects were all reported in accordance with best practices in quantitative educational research.

In sum, this research methodology combines rigorous quantitative procedures with robust theoretical grounding to investigate a complex, multi-pathway model of student learning outcomes. It reflects an integrative perspective that links institutional design, psychological engagement, individual aspirations, and educational achievement within a rapidly evolving vocational education landscape.

Results

This section presents the empirical findings of the study based on a sample of 475 vocational college students from various provinces in China. The analyses are organized to reflect the logic of the research framework, progressing from descriptive analysis of demographic and core variables, to measurement reliability and validity checks, and finally to hypothesis testing using regression analysis and structural equation modeling. The results aim to evaluate the relationships among data-driven personalized learning pathways, institutional support, learning engagement, career aspiration, and student academic and skills performance.

The descriptive statistical analysis begins with a profile of the respondents. Gender distribution was well-balanced, with male students comprising 49.1% of the sample and female students 50.9%. In

terms of age, the majority of participants were between 18 and 21 years old, consistent with the age range typical of vocational education students. Regarding grade level, 45.9% of the students were juniors, followed by sophomores (19.4%), freshmen (8.0%), and others (26.7%). As for academic major, engineering and manufacturing were the most represented disciplines (26.5%), followed by business and management (25.3%), information technology (22.1%), design and media (14.9%), and others (11.2%).

Family education background revealed that 34.5% of students reported the highest educational attainment of their parents as high school (including vocational education), 34.9% as associate degree, 17.7% as bachelor's degree, and 12.8% as master's degree or higher. In terms of self-perceived academic performance, the sample was relatively balanced: 19.8% of respondents rated themselves in the bottom 20% of the class, 24.6% below average, 21.7% as average, 21.1% as above average, and 12.8% in the top 20%. This distribution suggests sufficient variation across demographic and academic characteristics to support robust subgroup comparisons and multivariate analysis.

Descriptive statistics for the core constructs, all measured on 7-point Likert scales, were also analyzed. The mean score for personalized learning pathways was 5.31 (SD = 0.71), indicating a relatively strong student perception of data-driven and adaptive learning experiences. Institutional support had a mean score of 5.25 (SD = 0.74), reflecting generally positive perceptions of the learning infrastructure and instructional environment. Learning engagement received a mean score of 5.07 (SD = 0.81), showing moderate-to-high levels of behavioral, emotional, and cognitive involvement in learning. Career aspiration was rated slightly higher (M = 5.39, SD = 0.77), suggesting that students had relatively clear future vocational goals. Finally, academic and skills performance was rated at 5.18 (SD = 0.76), suggesting that students overall expressed confidence in both their academic outcomes and skill acquisition.

Before proceeding to hypothesis testing, the reliability and validity of the measurement instruments were thoroughly examined. Cronbach's alpha values for all constructs exceeded 0.87, with composite reliability values ranging from 0.89 to 0.93, indicating excellent internal consistency. Confirmatory factor analysis demonstrated acceptable model fit, with key indices including $\chi^2/df = 2.14$, CFI = 0.942, TLI = 0.934, RMSEA = 0.052, and SRMR = 0.047. The average variance extracted (AVE) for each construct was above the threshold of 0.50, and standardized factor loadings ranged from 0.58 to 0.87, supporting convergent validity. Discriminant validity was also verified using the Fornell-Larcker criterion, as the square root of AVE for each construct exceeded its correlations with other constructs. These findings validated the adequacy of the measurement model for use in subsequent structural modeling.

Correlation analysis revealed strong and statistically significant relationships between all core variables. Personalized learning pathways were highly correlated with academic and skills performance ($r = 0.965, p < .01$), and institutional support also showed a strong positive correlation with performance

($r = 0.839$, $p < .01$). Learning engagement was positively correlated with both personalized learning ($r = 0.778$) and academic outcomes ($r = 0.778$), while career aspiration showed moderate to strong associations with both engagement and performance. These correlations not only confirm theoretical expectations but also support the need for further exploration through regression and mediation modeling.

Multiple linear regression analysis was used to test the predictive power of personalized learning pathways and institutional support on academic and skills performance. The regression model explained 87.2% of the variance in student performance ($R^2 = 0.872$), with both independent variables being statistically significant predictors. Personalized learning pathways had a standardized beta coefficient of 0.662 ($t = 14.550$, $p < .001$), and institutional support had a larger coefficient of 0.934 ($t = 54.262$, $p < .001$), highlighting the relative importance of structural enablers such as teacher support and digital infrastructure. The F-value of 187.499 ($p < .001$) confirmed the overall significance of the regression model.

To examine the mediation hypothesis, structural equation modeling was employed. The total effect of personalized learning on student performance was statistically significant ($\beta = 0.4524$, $p < .001$). When learning engagement was included in the model as a mediator, the direct effect of personalized learning decreased to 0.2420, while the indirect effect via engagement was 0.2104. A bootstrap test based on 5,000 resamples yielded a 95% confidence interval for the indirect effect ([0.1668, 0.2586]) that did not include zero, confirming the presence of a significant partial mediation. The standardized indirect effect (0.3094) was nearly equivalent in magnitude to the direct effect, underscoring the critical role of learning engagement in translating personalized learning experiences into improved student outcomes. These findings support the assertion that student engagement acts as a cognitive-affective conduit through which instructional design features exert their influence on educational performance.

Beyond testing mediation, this study investigated the moderating role of career aspiration in the relationship between learning engagement and student performance. A hierarchical regression approach was adopted. The first model included learning engagement as the sole predictor of student performance and revealed a strong positive effect ($\beta = 0.761$, $t = 24.345$, $p < .001$). Adding career aspiration to the model in the second step slightly reduced the beta for engagement ($\beta = 0.576$, $t = 16.021$, $p < .001$), confirming that both variables contributed independently to predicting outcomes. In the third step, the interaction term between engagement and career aspiration was introduced and found to be statistically significant ($\beta = -0.063$, $t = -2.040$, $p = .042$). This result indicates that the positive effect of learning engagement on student performance was negatively moderated by the level of career aspiration. Specifically, for students with high career aspirations, the incremental benefit of increased engagement on performance was weaker than for students with lower career ambition. This moderating effect offers a nuanced understanding of learner diversity, suggesting that even effective engagement strategies may

yield differential outcomes depending on students' motivational profiles and future goals.

Overall, the results of this study confirm the validity of the proposed conceptual model. Data-driven personalized learning pathways and institutional support both have significant direct effects on student academic and skills performance. Learning engagement mediates the relationship between personalization and outcomes, revealing a psychological mechanism through which adaptive educational design enhances learning success. Career aspiration moderates the influence of engagement on performance, highlighting the contextual sensitivity of personalized learning's impact across individual motivational differences. These findings contribute valuable empirical evidence to the literature on personalized learning in vocational education, reinforcing the importance of both system-level enablers and learner-level variables in shaping educational effectiveness.

Discussion

The findings of this study provide significant empirical and theoretical insights into the mechanism by which data-driven personalized learning pathways influence the academic and skills performance of students in Chinese vocational education. The results confirm the validity of the conceptual framework grounded in Self-Determination Theory, Engagement Theory, and Social Cognitive Career Theory. By examining the direct, mediating, and moderating effects of key constructs within a structural model, this study advances a more nuanced understanding of how personalized learning functions in technology-enhanced educational contexts.

To begin with, the verification of the direct effects reveals that both personalized learning pathways and institutional support significantly and positively influence student academic and technical performance. Specifically, students who perceived a higher degree of learning personalization tended to report better outcomes in both academic achievements and skill development. This supports the theoretical expectation that personalized learning fosters autonomy, goal relevance, and instructional alignment—core elements known to enhance motivation and outcomes (Pane et al., 2017; Walkington, 2013). Notably, institutional support emerged as an even stronger predictor of performance, with a standardized regression coefficient significantly higher than that of personalized learning itself. This finding echoes Zeng et al. (2024), emphasizing the enabling role of institutional conditions—including platform stability, resource availability, and teacher support—in enhancing or inhibiting the actual functioning of personalization strategies.

In analyzing the underlying psychological mechanisms, the study provides robust evidence for the mediating role of learning engagement. The mediation test revealed that engagement partially transmits the effect of personalized learning on student outcomes, with a substantial indirect effect. This suggests that personalized learning is not merely about surface-level content delivery adjustments, but also about activating the learner psychologically—through fostering active participation, emotional involvement, and cognitive engagement. These findings resonate with the tenets of Self-Determination

Theory, which asserts that when autonomy and competence are supported by the learning environment, learners experience enhanced intrinsic motivation and are more likely to invest effort and persistence in learning activities (Ryan & Deci, 2000). The observed engagement effect also aligns with Kahu's (2013) process model, which conceptualizes engagement as a dynamic mediator linking external instruction and internal learning outcomes.

Beyond the mediation pathway, this study explored how career aspiration moderates the effect of learning engagement on academic and skills performance. Interestingly, the data revealed a statistically significant negative moderation effect. For students with high levels of career aspiration, the positive effect of engagement on performance was slightly attenuated. This suggests that such students may already be internally motivated and goal-oriented, thereby relying less on external engagement behaviors to achieve learning outcomes. In contrast, students with lower career aspirations seem to benefit more directly from higher engagement levels. This finding contributes to the literature by highlighting a boundary condition in the effectiveness of engagement strategies and confirms the core idea of Career Construction Theory, which emphasizes that a student's future career vision shapes not only their long-term identity development but also their immediate educational behaviors (Savickas, 2005). From an educational standpoint, this result suggests that "one-size-fits-all" strategies to improve engagement may have differentiated effects across student profiles.

Another critical point in the discussion concerns the theoretical alignment of these findings with existing research. The confirmation of the direct positive effects of personalized learning pathways and institutional support reinforces the general body of empirical evidence that supports personalization as an effective instructional strategy (Pane et al., 2015; Holmes et al., 2019). The centrality of learning engagement as a mediating mechanism is also consistent with a wide range of prior studies that have conceptualized engagement as a behavioral, emotional, and cognitive construct critical to academic success (Fredricks et al., 2004; Reeve, 2012). This consistency not only lends credibility to the present study's conclusions but also validates the theoretical assumptions embedded in the structural model.

However, this study goes beyond replication of established results. By introducing career aspiration as a moderator, the research advances a novel conceptual layer. While prior literature has explored the influence of individual differences such as self-efficacy, grit, and goal orientation, few studies have examined how career planning and future-orientation interact with learning processes in personalized educational settings. This study demonstrates that career aspiration is not merely a motivational predictor but also a context-sensitive moderator that shapes how students respond to learning design features. This insight enriches the personalization discourse by illustrating that learner characteristics must be incorporated not only as inputs but also as contingent conditions affecting outcomes.

Furthermore, the finding that institutional support exerts a stronger influence than personalization itself underscores the systemic nature of learning success. Even the best-designed

personalization mechanisms may falter in the absence of sufficient infrastructure, qualified teaching support, and responsive resource management. This highlights the importance of ecosystem design in educational innovation, wherein technological personalization must be embedded within supportive institutional cultures and governance structures.

In synthesizing the findings, this study affirms that data-driven personalized learning is a viable and valuable approach in vocational education. However, its success depends on both psychological mediators and contextual enablers. Personalized instruction enhances performance not only because it delivers tailored content, but because it fosters internalized motivation and behavioral engagement. Institutional environments reinforce or weaken this effect, while individual career goals condition its intensity. This multi-pathway model thus provides a richer and more flexible framework for designing, implementing, and evaluating educational interventions in digitally transformed learning environments.

In conclusion, the study advances the field by offering three key contributions. Theoretically, it integrates three influential theories—Self-Determination Theory, Engagement Theory, and Career Construction Theory—into a coherent analytical model that explains how and why personalized learning works. Methodologically, it employs a robust quantitative framework including structural equation modeling, mediation and moderation testing, and rigorous validity and reliability analysis to substantiate the hypothesized relationships. Practically, the study provides actionable insights for educators, institutional leaders, and policymakers seeking to improve student outcomes in vocational education through data-driven instructional design.

Conclusion

This study set out to explore the impact of data-driven personalized learning pathways on the academic and skills performance of vocational college students in China, with particular attention to the mediating role of learning engagement and the moderating effect of career aspiration. The findings offer a comprehensive and empirically substantiated response to the research questions initially posed and provide significant insights into how personalized instructional strategies function in digitally-enhanced educational environments, particularly within the context of vocational education.

The empirical evidence gathered in this study confirms that data-driven personalized learning pathways significantly and positively influence student outcomes. Students who perceived higher levels of personalization in their learning environments—manifested through adaptive content, real-time feedback, and self-paced progression—reported better academic achievement and more effective skills acquisition. These findings reinforce the claim that when instructional design is responsive to individual learner needs, interests, and behaviors, it enhances both motivation and competence, which in turn translate into measurable performance outcomes. This result lends further support to the growing body of literature that validates personalized learning as an effective pedagogical strategy in the age of big data and artificial intelligence in education.

Equally significant is the finding that institutional support plays a crucial, and perhaps even more substantial, role than personalization itself in shaping student performance. In contexts where institutions provide robust digital infrastructure, qualified and proactive teaching staff, and easy access to learning resources, students are more likely to benefit from any form of instructional innovation. This highlights the interdependence between technological tools and institutional readiness: while personalization mechanisms offer potential, they cannot operate in isolation. Institutional support acts as both a structural precondition and an amplifying factor for the success of personalized learning. Without strong infrastructural and organizational backing, even the most sophisticated adaptive learning systems may fail to yield desired educational effects.

The mediating role of learning engagement uncovered in this study underscores the importance of considering students' internal cognitive, emotional, and behavioral processes in any educational reform. Personalized learning does not operate purely at the content-delivery level; it functions through activating the learner's psychological investment in the learning process. The strong indirect effect observed in the structural equation model demonstrates that when students are emotionally connected to the material, behaviorally involved in tasks, and cognitively invested in understanding and applying concepts, they are significantly more likely to achieve high levels of academic and technical performance. This reinforces the theoretical foundations of both Self-Determination Theory and Engagement Theory and highlights the necessity for educators and instructional designers to move beyond surface-level interventions and toward strategies that stimulate deeper learner involvement.

The moderating role of career aspiration introduces a novel dimension to the current understanding of personalized learning. It suggests that students' perceptions of their future careers influence the extent to which they can benefit from engagement-based learning interventions. Specifically, students with high levels of career aspiration—those who have clear vocational goals and strong future orientation—may be less reliant on engagement behaviors to perform well academically. Conversely, students with lower career clarity appear to depend more heavily on engagement mechanisms to achieve performance outcomes. This dynamic reveals the limitations of uniform intervention strategies and underscores the need for more tailored instructional and motivational approaches that take into account the diversity of student aspirations and psychological profiles.

In terms of theoretical contributions, this study offers an integrated framework that brings together Self-Determination Theory, Engagement Theory, and Social Cognitive Career Theory. It demonstrates how personalization strategies (aligned with autonomy and competence), engagement processes (reflecting motivational and behavioral investment), and individual aspiration (as a form of future-oriented self-regulation) interact to produce educational outcomes. This integrated approach extends previous models that have traditionally treated these constructs in isolation and introduces a more holistic, multi-level understanding of how students experience and respond to educational innovations. By doing so, it addresses a notable gap in the literature and provides a robust foundation

for further empirical exploration and theoretical refinement.

The study also makes a notable methodological contribution by employing a comprehensive quantitative approach that integrates confirmatory factor analysis, structural equation modeling, mediation and moderation analysis, and bootstrap estimation. The large and diverse sample, rigorous instrument validation, and advanced statistical modeling provide a level of robustness and credibility that strengthens the generalizability of the findings. Moreover, the use of a multi-dimensional outcome variable (academic and skills performance) reflects the complexity of learning in vocational education and responds to calls for more nuanced assessments of student outcomes beyond traditional academic metrics.

From a practical standpoint, the implications of this study are substantial. For educators, the findings point to the importance of fostering engagement not merely through increased content delivery but through intentional design that addresses students' emotional, cognitive, and behavioral dimensions. Teachers should be trained to interpret learning analytics meaningfully and to intervene at critical points in the learning process with differentiated support based on student profiles. Curriculum designers should consider how adaptive learning platforms can be integrated into pedagogical strategies in ways that promote both autonomy and guidance. Importantly, these interventions must be sensitive to the diversity of student motivations and career goals; what works for highly motivated learners may not work for those with lower vocational clarity.

For institutional leaders, the study reinforces the need to invest in a coherent ecosystem that supports personalized learning—not only in terms of hardware and software, but also in faculty development, policy alignment, and cultural change. Personalized learning cannot succeed without systemic institutional readiness. Investments should prioritize flexible curricula, teacher digital competency, data literacy, and cross-departmental collaboration. At the policy level, educational authorities should consider how frameworks for digital transformation and vocational modernization incorporate personalization principles while ensuring equity and accessibility.

This study also acknowledges several limitations that warrant consideration. First, the cross-sectional nature of the data limits causal inferences. Although structural modeling provides strong evidence for directional relationships, longitudinal or experimental designs would offer stronger confirmation of causality. Second, all data were self-reported, which introduces the possibility of common method bias and social desirability effects, although measures were taken to mitigate these risks. Third, the study focused solely on vocational institutions in China; future research could examine how cultural and institutional variations affect the implementation and efficacy of personalized learning strategies across different contexts. Fourth, while this study focused on digital personalization, future research may explore hybrid models that combine algorithmic adaptation with human judgment and mentorship to enhance effectiveness and student satisfaction.

Future research should consider extending this model in several directions. Longitudinal studies

could explore how student engagement and career aspirations evolve over time and how sustained exposure to personalized learning affects long-term academic and career outcomes. Mixed-method studies could provide deeper insights into students' lived experiences with personalized learning platforms and how their psychological states influence technology acceptance and usage. Additionally, comparative studies across institutional types, regions, or countries could reveal important contextual moderators that shape the effectiveness of personalization strategies.

Moreover, future studies might expand the model to include other relevant variables such as self-regulated learning strategies, digital literacy, teacher-student relationships, and organizational culture. Exploring how these additional factors interact with personalized learning systems could lead to more refined models and targeted interventions. Another promising direction is to investigate how artificial intelligence and machine learning algorithms can be optimized not only for content recommendation but also for motivational scaffolding, engagement prediction, and career planning support. As AI in education continues to evolve, understanding its alignment with psychological and pedagogical principles will be critical.

In conclusion, this study offers a comprehensive and empirically grounded model of how data-driven personalized learning pathways influence student outcomes in vocational education, mediated by engagement and moderated by aspiration. It contributes to the theoretical refinement of personalization, advances methodological rigor in educational research, and offers actionable insights for teaching, institutional practice, and policy reform. As vocational education systems worldwide grapple with the challenge of providing personalized, effective, and scalable learning experiences, the findings of this study provide a valuable roadmap for designing student-centered, data-informed, and future-ready educational models.

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