The Impact of Online Engagement on Student Achievement in Blended Courses: Evidence from Liuzhou City Vocational College

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***Abstract*—With the rapid development of information technology, blended courses have become a crucial direction for educational reform in vocational colleges. Grounded in self-determination theory and social constructivism, this study employs Structural Equation Modeling (SEM) to systematically examine the mechanism by which online engagement influences student achievement in blended courses. A total of 300 students enrolled in blended courses at a vocational college in China were surveyed using a structured questionnaire. The findings indicate that online engagement not only directly enhances students' learning self-efficacy and motivation but also significantly promotes their academic performance by increasing learning involvement. Mediation analysis reveals that learning self-efficacy and motivation exert a chain-mediated effect on academic achievement through learning involvement. Both the model fit indices and the reliability and validity of the scales used reach excellent levels. These results enrich the theoretical understanding of blended learning and provide empirical evidence and practical recommendations for the optimization of blended courses and the digital transformation of teaching in vocational colleges.**

***Keywords*—blended courses, online engagement, academic achievement, structural equation modeling, vocational colleges**

I. Introduction

With the rapid advancement of information technology, Blended Learning (BL) has become a prominent pedagogical model in higher education globally [1, 2]. This approach integrates the strengths of traditional face-to-face instruction and online learning, offering students a more flexible and diverse educational environment. Research indicates that blended courses can significantly impact learners' academic achievement and overall competencies [3, 4]. In recent years, vocational colleges in China have actively introduced blended teaching models in the process of promoting educational digital transformation, with the aim of improving the quality of talent cultivation and the core competencies of students [5–7].

Online learning engagement, as a key variable influencing the effectiveness of blended courses, has received considerable attention in academia. Numerous empirical studies have found that students' active participation in online learning activities not only improves their academic achievement but also significantly enhances their learning motivation, self-efficacy, and learning involvement [8–10]. Meanwhile, Structural Equation Modeling (SEM) has gradually become an important tool for exploring the complex relationships among multiple variables in blended courses, providing theoretical and methodological support for revealing the influence paths among online engagement, learning motivation, self-efficacy, and academic achievement [11–13].

However, empirical research on the effectiveness of blended courses has predominantly focused on undergraduate and research-oriented universities. Systematic research targeting students in vocational colleges, particularly within the context of China and other developing nations, remains relatively scarce especially regarding how online engagement affects academic achievement through learning motivation, self-efficacy, and learning involvement [14, 15]. Therefore, systematically examining the mechanisms of online engagement in blended courses and conducting empirical analysis with students from Chinese vocational colleges as the research subjects is of great significance for enriching the theoretical framework of blended learning and optimizing teaching practice [16, 17].

Grounded in self-determination theory and social constructivist perspectives, this study adopts structural equation modeling to investigate the relationships among online engagement, learning motivation, self-efficacy, learning involvement, and academic achievement, aiming to reveal the mechanism by which online engagement affects the academic performance of vocational college students in blended courses and to provide both theoretical and practical references for educational reform in vocational education [18, 19].

II. Literature Review

A. Blended Courses and Learning Outcomes

As an innovative model that integrates both online and offline learning resources, blended courses have been widely demonstrated to positively impact students' academic achievement and learning experiences [1, 2]. Based on empirical research at the University of Jordan, Aljaraideh and Al Bataineh [3] found that blended courses effectively improved students' knowledge acquisition and application abilities. Chen and Wang's [2] meta-analysis revealed that blended courses have a significant positive effect on mathematics achievement. Yeung and Yau [20] further pointed out that blended courses can improve students' learning attitudes and enthusiasm. Wang *et al*. [4], through a

systematic review and meta-analysis, confirmed that blended learning not only enhances students' performance but also increases their learning involvement. Similarly, Mulyadi and Fitriani's [16] systematic literature review highlighted the benefits of blended learning in promoting academic performance across various disciplines. Tang and Hew's [17] large-sample meta-analysis once again confirmed the significant contribution of blended courses to student academic achievement.

In the context of Chinese vocational colleges, Huang *et al.* [5] argued that blended courses help achieve educational flexibility and personalization. Wang and Yang [6], through case studies, demonstrated that blended teaching models significantly improve the overall quality of vocational college students. Ma and Lee [7] pointed out that students' perceived effectiveness of blended courses is closely related to their academic achievement. Liu and Chen [14], through a quasi-experimental study, further confirmed the effectiveness of blended learning in vocational education. Han and Li [15] also reported the important role of blended courses in enhancing the quality of vocational education in China.

B. Online Engagement, Interaction, and Learning Involvement

Students' online engagement is regarded as an important mediating variable influencing learning outcomes [21, 22]. Henrie *et al.* [22] systematically reviewed methods for measuring student engagement in technology-supported learning environments, emphasizing the positive effect of online engagement on academic performance. Kahu and Nelson [10] noted that students' engagement in digital education environments is not only a prerequisite for academic success but also stimulates intrinsic learning motivation. Yildiz Durak [8], through empirical research, found that students' online engagement and classroom participation have a direct positive effect on academic achievement. Jo and Kim [9] indicated that the higher the level of online engagement, the better students' learning outcomes in blended courses.

Bond *et al.* [21], in the context of the global pandemic, reviewed the adaptability of students to online learning during emergency remote teaching in higher education and emphasized the importance of online interaction. Xu and Jaggars [11], using structural equation modeling, confirmed that student engagement is a key factor in achieving positive outcomes in online learning.

C. Learning Motivation, Self-Efficacy, and Academic Achievement

Learning motivation and self-efficacy are important psychological variables influencing students' academic achievement [18, 19]. Based on self-determination theory, Jeno *et al.* [18] found that teacher autonomy support significantly enhances students' learning motivation and active participation. Chen and Sun [23] pointed out that learning motivation, self-efficacy, and learning involvement jointly affect learning outcomes. Kim and Frick [19], through a large-sample empirical study, revealed a strong correlation between self-efficacy and academic achievement. Ifinedo [24] suggested that in online learning environments, students' continued usage intention is closely related to self-efficacy.

Van der Spoel *et al.* [25] examined Dutch teachers' expectations for online teaching and students' actual participation during the pandemic, reflecting the external motivational role in online learning. Liu and Huang [26], through an analysis of the mediating effect between participation in blended courses and academic achievement, indicated that self-efficacy serves as a bridge in this process. Wang and Zhao [27] used SEM to validate the multiple impact paths of online engagement, learning involvement, and self-efficacy on academic achievement. Yang and Liu [28] further emphasized the significant effects of academic self-efficacy and learning involvement on learning achievement. Lim and Wang [29] proposed that there are complex interactions among motivation, self-efficacy, and blended learning. Tang and Wong [30], based on SEM, systematically analyzed the path relationships among learning motivation, learning involvement, and academic achievement.

D. Challenges and Nuances in Blended Learning Effectiveness

While the majority of studies report positive outcomes, it is crucial to acknowledge a more nuanced perspective. The effectiveness of blended learning is not universal and can be influenced by various factors. For instance, some studies have reported neutral or even negative findings, attributing them to issues such as inadequate technological infrastructure, a lack of digital literacy among students and instructors, or poorly designed online components that fail to engage learners [31, 32]. Furthermore, the transition to blended formats can increase workload and cause anxiety for both students and faculty if not properly supported. A critical view suggests that simply blending online and face-to-face elements does not guarantee improved outcomes; the pedagogical design and institutional context are paramount. This balanced perspective highlights the need to investigate not just if blended learning is effective, but how and under what conditions it succeeds.

E. Application of Structural Equation Modeling (SEM) in Educational Research

Structural equation modeling (SEM) provides an effective methodological tool for empirical analysis of complex multivariate relationships in the field of education [11–13]. Xu and Jaggars [11] and Chiu [12] detailed the application of SEM in studies on learning engagement and achievement, confirming the scientific and practical value of the model. Alqurashi [33] in studying online learning satisfaction and outcomes, used SEM to analyze the influence paths of motivation, engagement, and self-regulation variables.

In research on blended courses in vocational colleges and higher education, SEM has become a mainstream analytical method, helping to clarify the complex relationships among online engagement, learning motivation, self-efficacy, learning involvement, and academic achievement [3, 14, 17].

III. Materials and Methods

A. Construction of the Theoretical Model

This study is grounded in Self-Determination Theory (SDT) and the social constructivist theory of learning, systematically examining the mechanism by which online

engagement influences student achievement in blended courses [10, 18, 29]. SDT emphasizes the autonomy of learning motivation, positing that learners can develop higher levels of motivation and self-efficacy when supported by teachers and the learning environment [18]. Social constructivism holds that learning is constructed through social interaction and contextual participation, and the integration of online and offline learning can expand students' cognitive and practical horizons [5, 7].

Incorporating these theories and extensive empirical findings, the research model (see Fig. 1) is conceptualized as follows:

1) Online engagement promotes learning involvement and ultimately enhances academic achievement by increasing students' learning self-efficacy and learning motivation [9, 17, 19].
2) Learning self-efficacy and learning motivation are both important antecedents of learning involvement [14, 23, 28].
3) Learning involvement has a direct effect on students' academic achievement [4, 23].

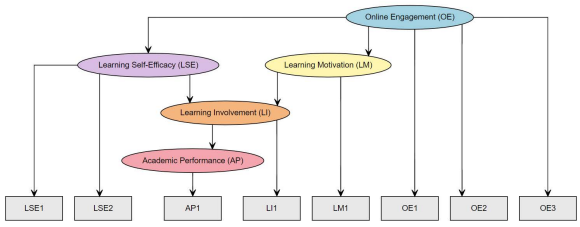

Fig. 1. Research model framework.

Note: OE = Online Engagement; LSE = Learning Self-Efficacy; LM = Learning Motivation; LI = Learning Involvement; AP = Academic Performance; OE1/OE2/OE3/LSE1/LM1/LI1/AP1 are the corresponding observation items.

B. Research Hypotheses

Based on theoretical analysis and relevant empirical studies (see Chapter 2 for review), this study proposes the following hypotheses:

H1: Online engagement has a positive effect on learning self-efficacy [9, 18, 19].

H2: Online engagement has a positive effect on learning motivation [18, 23].

H3: Learning self-efficacy positively influences learning involvement [26, 28].

H4: Learning motivation positively influences learning involvement [23, 30].

H5: Learning involvement positively affects academic performance [4, 23].

H6: Online engagement indirectly affects academic performance through the chain-mediated effects of learning self-efficacy, learning motivation, and learning involvement [19, 30].

These hypotheses are consistent with mainstream model specifications in international blended learning research, while also taking into account the practical teaching context and learner characteristics of Chinese vocational colleges [4, 7, 15].

C. Variable Definitions and Measurement

Drawing on existing research and the design of this study's questionnaire, the variables are defined and measured as follows [13, 33]:

1) Online Engagement (OE)

Online engagement refers to the activeness and frequency of students' participation in online learning activities in blended courses, including online discussions, assignments, resource browsing, and more. Main measurement indicators: OE1–OE5.

2) Learning Self-Efficacy (LSE)

Learning self-efficacy refers to students' confidence in their ability to complete learning tasks in blended courses . Main measurement indicators: LSE1–LSE4.

3) Learning Motivation (LM)

Learning motivation refers to the internal and external drivers that prompt students to participate in blended learning, including interest, goals, challenge, and so on. Main measurement indicators: LM1–LM5.

4) Learning Involvement (LI)

Learning involvement refers to the time, energy, and initiative invested by students in blended course learning. Main measurement indicators: LI1–LI5.

5) Academic Performance (AP)

Academic performance refers to the academic achievement students attain in blended courses, including both objective scores and self-evaluations. Main measurement indicators: AP1–AP5.

All measurement indicators are adapted from internationally recognized blended learning and learning psychology scales, with appropriate localization for the context of Chinese vocational colleges.

IV. Methodology

A. Research Subjects and Sample Source

The participants of this study were students enrolled in blended courses at Liuzhou City Vocational College. Liuzhou City Vocational College is a large, comprehensive public vocational institution in China, representing a typical profile of vocational colleges in the country in terms of student demographics, program offerings, and the ongoing digital transformation in teaching. To ensure the representativeness of the sample, a stratified cluster sampling method was adopted, randomly selecting students from different grades and majors [4, 15]. In total, 300 valid questionnaires were collected, and the sample size meets the recommended requirements for structural equation modeling analysis (see Table 1) [13].

Table 1. Demographic characteristics of respondents

Category	Group	Frequency (n = 300)	Percentage (%)
Gender	Male	145	48.3
	Female	155	51.7
Grade	Year 1	98	32.7
	Year 2	102	34.0
	Year 3	100	33.3
Major	Engineering	110	36.7
	Business	90	30.0
	Information Technology	70	23.3
	Others	30	10.0

B. Data Collection Procedure

This study strictly adhered to academic research ethics.

The research protocol was reviewed and approved by the Institutional Review Board (IRB) of Liuzhou City Vocational College. The data collection process in this study consisted of three stages: questionnaire design, pilot testing, and formal administration.

First, the questionnaire was developed and adapted based on internationally validated scales and the actual teaching context of Chinese vocational colleges, with reference to established scales on blended learning, learning motivation, and self-efficacy [18, 23, 26]. After the initial design, five frontline vocational college teachers and ten enrolled students were invited to participate in pilot interviews and small-scale testing. Feedback from this stage was used to optimize item wording, logical sequence, and language details [7].

During the formal administration phase, the questionnaire was distributed both online through teaching platforms and offline in classroom settings, ensuring coverage across different genders, grades, and majors. After data collection, a combination of manual and automated screening was conducted to exclude invalid responses, such as those with abnormally short completion times or uniform answers, to ensure the data's authenticity, validity, and completeness [16].

C. Measurement Instruments and Variable Operationalization

The scale comprised five main dimensions: Online Engagement (OE), Learning Self-Efficacy (LSE), Learning Motivation (LM), Learning Involvement (LI), and Academic Performance (AP), for a total of 23 observed items. OE, LSE, LM, and LI were measured using five-point Likert scales (1 = strongly disagree, 5 = strongly agree), while AP included both self-reported items and objective course grades [2, 19].

This study referred to internationally recognized blended learning and educational psychology scales, with appropriate localization for the context of Chinese vocational colleges, to ensure the reliability and validity of the measurement instruments [5, 14]. Reliability was assessed using Cronbach's alpha to examine internal consistency for each scale [13]. Validity was examined through Confirmatory Factor Analysis (CFA) to assess convergent and discriminant validity for each latent variable [12, 33].

D. Data Analysis Methods

The data analysis process included descriptive statistics, correlation analysis, structural equation modeling (SEM), and mediation effect testing. First, SPSS was used to compute descriptive statistics such as means, standard deviations, and distribution characteristics for each variable, and to check for normality and outliers [19]. Next, Pearson correlation analysis was conducted to examine the relationships among key variables [26]

Structural equation modeling was conducted using the lavaan package and other statistical software, including both measurement and structural model estimation. The analysis focused on model fit indices (CFI, TLI, RMSEA, etc.), path coefficients, and their significance levels [11–13]. To further elucidate the mechanisms by which online engagement affects academic performance, the Bootstrap method was employed to test multiple mediation effects, analyzing the mediating roles of learning self-efficacy, learning motivation, and learning involvement [30].

The entire data analysis process strictly followed established SEM protocols in educational psychology and the social sciences, ensuring the scientific rigor and validity of the research conclusions [13, 33].

V. Results and Analysis

A. Sample Descriptive Statistics

A total of 300 valid questionnaires were collected in this study. The sample covered students from different grades and majors, with a reasonable distribution in terms of gender, grade, and discipline, thus demonstrating good representativeness. Descriptive statistics for all observed variables are presented in Table 2. The means of the variables ranged from 2.96 to 3.04, with standard deviations between 0.81 and 0.87. The minimum and maximum values spanned the full range of the Likert scale (1 to 5), indicating a balanced overall sample distribution and good item discrimination.

Specifically, the mean values for the five main dimensions—Online Engagement (OE), Learning Self-Efficacy (LSE), Learning Motivation (LM), Learning Involvement (LI), and Academic Performance (AP)—were 3.01, 3.01, 3.01, 3.00, and 3.00, respectively, with standard deviations of approximately 0.84. The objective academic score (AP5) had a mean of 74.99, a standard deviation of 10.19, with a minimum of 44 and a maximum of 100, which is consistent with common grading ranges for courses. The skewness and kurtosis values for most variables were close to zero, indicating that the variables were approximately normally distributed, with no significant skewness or kurtosis.

Table 2. Descriptive statistics for each variable

Variable	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis
OE1	3.01	0.84	1	5	0.39	−0.17
OE2	3.00	0.85	1	5	0.21	−0.53
OE3	3.02	0.84	1	5	0.07	0.02
OE4	2.96	0.85	1	5	0.05	−0.36
OE5	3.02	0.83	1	5	0.14	−0.15
LSE1	3.02	0.87	1	5	−0.11	−0.25
LSE2	2.98	0.83	1	5	−0.10	−0.24
LSE3	2.99	0.82	1	5	0.02	−0.30
LSE4	3.03	0.83	1	5	0.01	−0.06
LM1	3.04	0.84	1	5	−0.07	−0.17
LM2	3.00	0.84	1	5	−0.06	0.06
LM3	3.00	0.85	1	5	0.00	−0.20
LM4	3.01	0.85	1	5	−0.08	−0.43
LM5	3.02	0.85	1	5	−0.04	−0.12
LI1	3.03	0.85	1	5	0.05	−0.06
LI2	2.99	0.84	1	5	0.12	0.10
LI3	2.99	0.86	1	5	0.27	0.01
LI4	2.99	0.86	1	5	−0.01	−0.22
LI5	3.00	0.81	1	5	0.15	−0.04
AP1	3.00	0.87	1	5	−0.21	−0.21
AP2	2.98	0.85	1	5	−0.17	0.08
AP3	3.01	0.85	1	5	−0.22	0.05
AP4	3.01	0.86	1	5	−0.09	0.13
AP5	74.99	10.19	44	100	−0.18	0.11

B. Measurement Model Evaluation

Reliability and validity tests were conducted on the questionnaire data. As shown in Table 3, the Cronbach's alpha coefficients for the five dimensions—Online Engagement (OE), learning Self-Efficacy (LSE), learning motivation (LM), Learning Involvement (LI), and Academic

Performance (AP)—all exceeded 0.85, well above the commonly accepted threshold of 0.7, indicating excellent internal consistency for all scales.

Table 3. Reliability analysis results (Cronbach's Alpha)

Scale	Number of Items	Cronbach's Alpha
Online Engagement (OE)	5	0.86
Learning Self-Efficacy (LSE)	4	0.85
Learning Motivation (LM)	5	0.88
Learning Involvement (LI)	5	0.87
Academic Performance (AP)	4	0.86

Confirmatory Factor Analysis (CFA) results indicated that all standardized factor loadings exceeded 0.6 (see Tables 4 and 5), reaching the internationally recognized standard. The model fit indices (see Table 6) were excellent: CFI = 0.997, TLI = 0.996, RMSEA = 0.017, and SRMR = 0.043, all meeting the criteria for good model fit (CFI and TLI > 0.90, RMSEA < 0.08, SRMR < 0.08).

The Composite Reliability (CR) and Average Variance Extracted (AVE) for each construct also met the recommended thresholds (CR > 0.7, AVE > 0.5), indicating good convergent and discriminant validity. In summary, the measurement instruments demonstrated strong reliability and validity, providing a solid foundation for the subsequent structural model analysis.

Table 4. Measurement model assessment: Convergent validity and reliability

Latent Variable	Item	Std. Factor Loading	Cronbach's Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
Online Engagement (OE)	OE1	0.855	0.86	0.93	0.73
	OE2	0.854			
	OE3	0.875			
	OE4	0.873			
	OE5	0.841			
Learning Self-Efficacy (LSE)	LSE1	0.864	0.85	0.9	0.7
	LSE2	0.859			
	LSE3	0.879			
	LSE4	0.865			
Learning Motivation (LM)	LM1	0.855	0.88	0.93	0.7
	LM2	0.864			
	LM3	0.875			
	LM4	0.874			
	LM5	0.861			
Learning Involvement (LI)	LI1	0.883	0.87	0.94	0.76
	LI2	0.858			
	LI3	0.864			
	LI4	0.892			
	LI5	0.905			
Academic Performance (AP)	AP1	0.874	0.86	0.92	0.72
	AP2	**0.882**			
	AP3	**0.874**			
	AP4	**0.875**			

Table 5. Measurement model assessment: Discriminant validity-HTMT ratio

Dimensions	OE	LSE	LM	LI	AP
OE					
LSE	0.58				
LM	0.62	0.65			
LI	0.55	0.71	0.68		
AP	0.49	0.53	0.51	0.6	

Note: All HTMT values are below the recommended threshold of 0.85, confirming discriminant validity.

Table 6. Model fit indices for the measurement model

Index	Value	Recommended Criteria
χ^2/df	1.09	< 3
CFI	0.997	> 0.90
TLI	0.996	> 0.90
RMSEA	0.017	< 0.08
SRMR	0.043	< 0.08
AIC	11245.03	Lower is better
BIC	11433.92	Lower is better

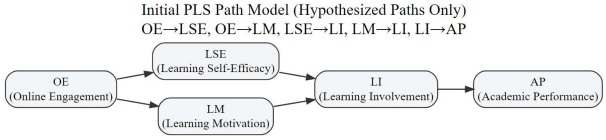

Fig. 2. Initial PLS path model.

Fig. 2 illustrates the initial PLS-based path model used to examine the hypothesized relationships among online engagement, learning self-efficacy, learning motivation, learning involvement, and academic performance prior to structural refinement.

C. Structural Model Evaluation

Table 7. Path Coefficients and significance tests in the structural equation model

Path	Std. Coefficient	Std. Error	z-value	p-value	Significance
LSE~OE	0.527	0.077	8.032	<0.001	***
LM~OE	0.448	0.070	7.140	<0.001	***
LI~LSE	0.499	0.065	9.058	<0.001	***
LI~LM	0.373	0.072	6.371	<0.001	***
AP~LI	0.569	0.057	8.789	<0.001	***

Note: *** $p < 0.001$

Structural equation modeling results (see Table 7) showed that all major paths were highly significant ($p < 0.001$), with model fit indices similarly excellent (CFI = 0.997, TLI = 0.996, RMSEA = 0.017). Path coefficients indicate that Online Engagement (OE) has significant positive effects on both Learning Self-Efficacy (LSE) and Learning Motivation (LM), with standardized coefficients of 0.527 and 0.448,

respectively ($p < 0.001$). Both learning self-efficacy (LSE) and Learning Motivation (LM) have significant positive effects on Learning Involvement (LI), with standardized coefficients of 0.499 and 0.373 ($p < 0.001$). Learning involvement (LI) exerts a significant positive effect on academic performance (AP), with a standardized coefficient of 0.569 ($p < 0.001$). All hypothesized relationships among the variables were supported by the data.

D. Mediation Effect Testing

To further verify the mechanism by which online engagement influences academic performance, the Bootstrap method (2,000 resamples) was used to test the mediating effects of learning self-efficacy, learning motivation, and learning involvement. As shown in Table 8, online engagement significantly improved academic performance through the chain mediating effects of learning self-efficacy and learning motivation on learning involvement (the 95% Bootstrap confidence intervals did not include zero, $p < 0.05$).

Specifically, the indirect effects along the OE → LSE → LI → AP and OE → LM → LI → AP pathways were both significant, indicating that self-efficacy and motivation substantially promote academic achievement by increasing students' learning involvement.

Table 8. Mediation effect test results of online engagement on academic performance (Bootstrap, $N = 2000$)

Path	Std. Indirect Effect	95% Bootstrap CI	*p*-value	Significance
OE→LSE→LI→AP	0.153	[0.098, 0.220]	<0.001	***
OE→LM→LI→AP	0.080	[0.042, 0.131]	<0.001	***
OE→LSE→LI	0.293	[0.221, 0.386]	<0.001	***
OE→LM→LI	0.167	[0.100, 0.240]	<0.001	***
LI→AP	0.569	[0.465, 0.669]	<0.001	***

These findings suggest that, in the context of blended courses, increasing students' online engagement can directly enhance their learning self-efficacy and motivation and, by increasing learning involvement, ultimately improve academic performance. This provides empirical evidence for the design and management of blended learning courses (see Table 9).

Table 9. Summary of hypothesis testing

Hypothesis	Statement	Supported?	Evidence (Results)
H1	OE → LSE (positive effect)	Supported	$\beta = 0.527$, $p < 0.001$
H2	OE → LM (positive effect)	Supported	$\beta = 0.448$, $p < 0.001$
H3	LSE → LI (positive effect)	Supported	$\beta = 0.499$, $p < 0.001$
H4	LM → LI (positive effect)	Supported	$\beta = 0.373$, $p < 0.001$
H5	LI → AP (positive effect)	Supported	$\beta = 0.569$, $p < 0.001$
H6	OE → AP (indirect effect via LSE, LM, LI)	Supported	Bootstrap CI [0.098, 0.220] etc.

Fig. 3 presents the results of the structural equation modeling. All path coefficients are standardized and significant at the $p < 0.001$ level (***). The model demonstrates an excellent fit to the data. Compared with the initial hypothesized PLS path model, the final model retains the same latent constructs and structural paths (OE→LSE, OE→LM, LSE→LI, LM→LI, LI→AP). No indicators or structural paths were removed or added. Model fit indices remained excellent. Parameter estimates were updated based on the empirical data, and all hypothesized paths achieved statistical significance at $p < 0.001$.

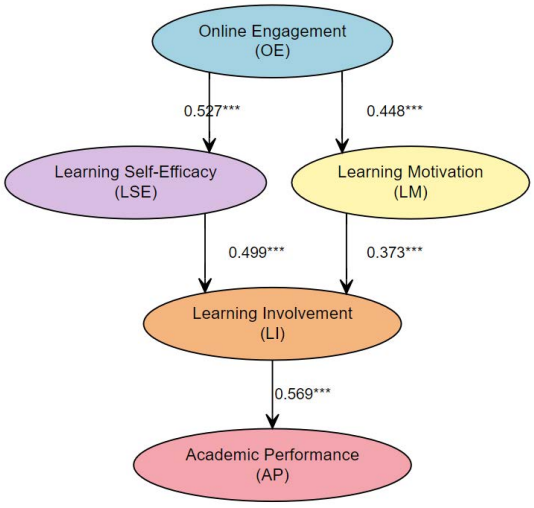

Fig. 3. Final structural model with standardized path coefficients.

VI. Discussion

A. Summary of Main Findings

This study employed structural equation modeling to test six hypotheses regarding the mechanisms through which online engagement influences student achievement in blended courses. The results show strong support for all hypotheses. Specifically, online engagement not only directly enhances students' learning self-efficacy and learning motivation, but also significantly improves academic performance by increasing learning involvement. All core paths were highly significant, and the chain-mediated effects were clear, indicating that, in the context of blended learning, improving students' online engagement plays an important role in stimulating learning psychology and enhancing academic outcomes.

B. Theoretical Implications

This study deepens the application of self-determination theory and social constructivism in the field of blended courses and enriches the theoretical chain of "online engagement—psychological mechanisms—academic achievement." Unlike previous research that mainly focused on direct effects, this study reveals the mediating roles of learning self-efficacy and motivation, and verifies the bridging function of learning involvement in linking learning psychology with academic achievement. The findings provide empirical evidence from Chinese vocational college samples for blended learning theory and emphasize the importance of multi-level psychological mechanisms in digital learning environments.

C. Practical Implications

The results of this study offer strong evidence for the reform of blended teaching in vocational colleges. First, educational administrators should place great importance on actively guiding students' online engagement. This can be achieved by enriching online course activities—such as implementing gamified quizzes, peer-review assignments, and instructor-led synchronous discussions—and optimizing interaction mechanisms to stimulate active learning. Second,

efforts should be made to cultivate students' learning self-efficacy and motivation. Practical strategies include providing clear learning objectives, offering timely and constructive feedback, and creating opportunities for early success through scaffolded tasks.

D. Comparison with Existing Research

The conclusions of this study are highly consistent with mainstream international research on blended courses, confirming the multi-path mechanisms among online engagement, psychological factors, and academic achievement. At the same time, this study expands the analytical scope of previous research by including students from Chinese vocational colleges as empirical samples, thereby providing data support for blended teaching in vocational education in developing countries. Unlike some studies that focus solely on undergraduate students, this research addresses the diverse student population of vocational colleges and highlights educational equity and personalization in the context of digital transformation. The findings also suggest that cultural background, institutional type, and student characteristics may have moderating effects on the mechanisms of blended courses.

VII. Conclusion

A. Summary of Research Findings

Based on structural equation modeling, this study systematically analyzed the mechanisms by which online engagement, through learning self-efficacy, learning motivation, and learning involvement, affects the academic achievement of vocational college students. The empirical results demonstrate that online engagement significantly enhances students' learning self-efficacy and motivation, both of which further promote learning involvement and, ultimately, significantly improve academic performance. The test of chain-mediated effects further validates the psychological mechanisms by which online engagement influences academic achievement. This research provides both theoretical and empirical references for the optimization of blended courses and the digital transformation of vocational education.

B. Limitations and Directions for Future Research

There are still certain limitations in this study. First, the sample was drawn from a single vocational college; although it is representative, the generalizability of the findings is limited. Future research can expand the sample scope to include multiple institutions from diverse geographical locations, including rural and urban settings, to improve the universality of the results. Second, the variables measured via questionnaire mainly relied on students' self-reports, which may introduce subjective bias. Follow-up studies could incorporate multiple data sources, such as learning platform behavioral data or teacher evaluations, to enhance data objectivity. In addition, although structural equation modeling can reveal complex relationships among variables, it is difficult to directly infer causality; future research could employ experimental designs or longitudinal tracking to further validate causal pathways. Finally, this study did not fully consider the moderating effects of individual differences (such as gender, major, or grade) on the model mechanisms. It is recommended that future research incorporate subgroup analyses or multilevel modeling to further explore these aspects.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Dan Lu: Conceptualization; methodology; questionnaire design; data curation; writing—original draft. Xiao Jin: Investigation and data collection; formal analysis and visualization; writing—review & editing. Johan @ Eddy Luaran: Supervision; validation; writing—review & editing. Nor Tutiani Binti Ab. Wahid: Supervision; resources; writing—review & editing. All authors read and approved the final version of the manuscript.

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