Research on the Influencing Factors and Optimization Strategies of College Students' Online Learning Sustainability

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Abstract: The rapid digital transformation of China's vocational education system has introduced extensive opportunities for flexible, technology-enhanced learning. However, sustaining long-term engagement in online learning environments remains an unresolved challenge, particularly among students enrolled in application-oriented majors such as Intelligent Transportation. The present study investigates the key factors influencing the sustainability of online learning and proposes practical optimization strategies to enhance students' continued participation and learning quality. Drawing upon self-regulation theory, expectancy–value theory, and the community of inquiry framework, this research conceptualizes online learning sustainability as the persistent, self-motivated, and value-driven engagement of learners in digital learning activities over time. Empirical data were collected through a structured questionnaire survey of 200 Chinese vocational college students majoring in Intelligent Transportation. The study utilized a five-point Likert scale to assess seven latent constructs—self-regulated learning (SRL), digital literacy (DL), institutional support (IS), teacher presence (TP), peer interaction (PI), motivation (MO), and perceived usefulness (PU)—as predictors of sustainability intention (SI). Statistical analyses included descriptive statistics, reliability testing, Pearson correlations, and standardized multiple regression. All measurement scales demonstrated satisfactory internal consistency (Cronbach's α = 0.84–0.87). The regression model revealed that SRL, MO, and PU exerted the strongest direct effects on SI, while IS, DL, and TP played important enabling roles. PI exhibited a smaller but significant positive influence, emphasizing the value of peer networks in maintaining engagement. Based on the empirical findings, the paper proposes twelve evidence-based strategies addressing institutional policy, digital infrastructure, instructional design, and learner support systems. These include developing analytics-based early-warning systems, enhancing teacher feedback cycles, integrating certification-oriented learning pathways, and strengthening self-regulation and motivation training. The study contributes both theoretically and practically to the growing discourse on sustainable online learning in vocational education, offering a replicable model and strategic roadmap for educators and policymakers seeking to align digital pedagogy with the objectives of China's high-quality vocational education reform.

Keywords: Online Learning Sustainability; Vocational Education; Self-regulated Learning; Motivation; Digital Literacy

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1 Introduction

The transformation of global higher education through digital technology has redefined how knowledge is produced, delivered, and sustained. Within this evolution, vocational education in China occupies a pivotal role as the nation transitions toward an innovation-driven, technology-intensive economy. The Intelligent Transportation industry, as one of the priority sectors in China's "Made in China 2025" and "New Infrastructure" initiatives, demands professionals who are not only technically competent but also capable of engaging in continuous, self-directed digital learning. Consequently, the ability of vocational students to sustain engagement in online learning environments has emerged as both an educational and industrial imperative.

Over the past decade, the Ministry of Education of the People's Republic of China has promoted large-scale digital reforms in vocational colleges. These include the construction of Smart Campuses, integration of 1+X certification systems, and development of online teaching resource banks for specialized disciplines such as intelligent logistics, automated traffic management, and connected vehicle technologies. However, despite the proliferation of online platforms, research consistently reports declining engagement and course completion rates after initial adoption [1]. This disengagement threatens not only individual learning outcomes but also the broader strategic goal of producing digitally adaptive, lifelong learners who can thrive in the emerging intelligent transportation sector.

1.1 The Problem of Sustainability in Vocational Online Learning

Online learning sustainability refers to learners' capacity and willingness to maintain effective, goal-oriented engagement in digital learning environments over time [2]. In vocational contexts, this means consistently participating in online modules, integrating digital simulations with practice, and applying newly acquired skills in workplace settings. Yet, vocational college students often exhibit inconsistent engagement—logging in sporadically, completing only mandatory assessments, and struggling to sustain self-regulated study habits without close supervision. Factors such as limited digital literacy, unstable motivation, and insufficient institutional scaffolding contribute to this pattern [3].

Unlike university students in academic disciplines, vocational students' motivation to learn online is often instrumental and career-oriented—linked to certification attainment or job readiness rather than intrinsic curiosity. This pragmatic orientation makes sustainability highly sensitive to perceived usefulness (PU) and institutional support (IS). At the same time, the effectiveness of online instruction depends heavily on teacher presence (TP) and peer interaction (PI), which can mitigate isolation and enhance perceived relevance [4]. Understanding how these multifaceted variables interact to influence sustainability intention (SI) is thus critical for educational administrators, instructional designers, and policymakers.

1.2 The Context of Intelligent Transportation Majors

Intelligent Transportation majors sit at the intersection of engineering technology, information systems, and mobility management. The curriculum typically integrates simulation-based courses in traffic signal control, intelligent vehicle networking, data analytics, and transportation planning software. Many learning modules are delivered online through industry-partnered platforms, combining theoretical content with virtual labs and certification tasks (e.g., VISSIM, Synchro, or ArcGIS-based modules). However, such digital complexity often exceeds the digital literacy of first- and second-year vocational students, creating a gap between curricular ambition and learner readiness. Moreover, online systems that mimic real-world traffic or logistics scenarios demand high self-regulation and sustained cognitive engagement—conditions not easily maintained in asynchronous learning environments.

The present study addresses this gap by empirically investigating the influencing factors that support or hinder sustainable online learning behaviors among Intelligent Transportation majors. It aims to identify both personal attributes (self-regulation, motivation, digital literacy) and contextual supports (teacher presence, institutional infrastructure, peer networks) that jointly determine sustainability. This dual perspective aligns with contemporary approaches to educational sustainability, which emphasize the balance between learner autonomy and institutional ecology.

1.3 Theoretical Underpinnings

The study is grounded in three complementary frameworks:

Self-Regulation Theory [5]:

Posits that sustained learning depends on goal setting, self-monitoring, and self-reflection. In online learning, SRL enables learners to maintain effort without direct supervision.

Expectancy–Value Theory [6]:

Suggests that learners' persistence is a function of perceived value and expectation of success. Motivation (MO) and perceived usefulness (PU) thus shape sustainability intention through cost–benefit judgments.

Community of Inquiry:

Emphasizes the interdependence of cognitive, social, and teaching presence in online education. Teacher presence (TP) and peer interaction (PI) reinforce learning persistence by fostering engagement and belonging.

By integrating these frameworks, the present research conceptualizes online learning sustainability as the outcome of interpersonal, intrapersonal, and institutional dynamics—a systems perspective particularly suited to vocational education where skill acquisition is tightly coupled with applied contexts.

1.4 Research Objectives and Significance

This study pursues two interrelated objectives:

Analytical Objective: To quantify the relative influence of SRL, DL, IS, TP, PI, MO, and PU on sustainability intention (SI) among vocational college students in Intelligent Transportation majors.

Strategic Objective: To develop optimization strategies that can guide policy, pedagogy, and technology integration for enhancing sustained online engagement.

The significance of this research is threefold. First, it provides empirical evidence on a domain that remains underexplored—vocational students' digital learning sustainability in applied engineering contexts. Second, it contributes a theoretically integrated model, bridging motivational, technological, and institutional perspectives. Third, it translates findings into practical interventions, aligning with China's 14th Five-Year Plan goals to improve the quality and sustainability of vocational education.

1.5 Research Questions and Hypotheses

The study addresses the following guiding questions:

What are the main psychological, technological, and institutional factors influencing online learning sustainability among vocational college students?

How do self-regulation, motivation, and perceived usefulness interact with contextual variables such as teacher presence and institutional support?

What optimization strategies can be developed to enhance sustainable online learning behaviors in Intelligent Transportation education?

Based on theoretical foundations and prior studies, seven hypotheses are proposed:

H1: Self-regulated learning (SRL) positively influences sustainability intention (SI).

H2: Digital literacy (DL) positively influences SI.

H3: Institutional support (IS) positively influences SI.

H4: Teacher presence (TP) positively influences SI.

H5: Peer interaction (PI) positively influences SI.

H6: Motivation (MO) positively influences SI.

H7: Perceived usefulness (PU) positively influences SI.

1.6 Structure of the Paper

Following this introduction, Section 2 provides a comprehensive literature review summarizing prior empirical and theoretical developments on online learning sustainability. Section 3 details the research design, including sample characteristics, measurement instruments, and analytical methods. Section 4 presents empirical findings with tables and figures, while Section 5 discusses interpretations and implications. Section 6 outlines optimization strategies for improving online learning sustainability in vocational contexts, and Section 7 concludes with recommendations for policy and future research.

2 Literature Review

2.1 Conceptualizing Online Learning Sustainability

Online learning sustainability has emerged as a critical construct in the discourse of educational technology and digital pedagogy. While early e-learning research focused primarily on adoption and initial satisfaction, more recent studies highlight the importance of continuance and sustained engagement. Sustainability in this context refers not merely to the intention to reuse online systems, but to persistent, meaningful participation that yields long-term academic or professional benefits. Scholars have empha-

sized that sustainability requires the convergence of cognitive self-regulation, motivational resilience, and supportive institutional environments [7].

In the context of vocational education, sustainability acquires an additional applied dimension. Vocational students must integrate online learning into practice-based competencies, linking theoretical understanding with workplace performance. Therefore, sustainable online learning entails maintaining active engagement across multiple learning cycles—classroom, laboratory, internship, and certification modules—while continuously updating digital and technical skills relevant to industry. This longitudinal perspective distinguishes sustainability from short-term course satisfaction or completion.

2.2 The Role of Self-Regulated Learning (SRL)

Self-regulated learning (SRL) has been widely recognized as the most powerful individual-level determinant of sustained academic performance in digital environments. SRL encompasses cognitive, metacognitive, and motivational processes that enable learners to plan, monitor, and evaluate their learning behaviors. Online environments, which lack the constant supervision of face-to-face classrooms, heighten the demand for these self-regulatory competencies.

Empirical research consistently links SRL to persistence in e-learning contexts. For instance, Barnard et al. [8] found that time management, self-efficacy, and goal setting were strong predictors of online course completion. In vocational education, however, SRL is often underdeveloped due to the students' prior dependence on teacher-led instruction. Developing SRL among vocational learners requires structured scaffolding—such as progress trackers, reflective prompts, and explicit goal-setting exercises. For Intelligent Transportation majors, who must manage multiple concurrent software and simulation modules, SRL supports the coordination of complex digital tasks and fosters cognitive endurance over long projects.

2.3 Digital Literacy and Online Learning Continuance

Digital literacy (DL) represents the technical and cognitive ability to access, evaluate, and apply digital information effectively. The concept extends beyond basic computer skills to encompass information literacy, media literacy, and digital communication competence [9]. Research indicates that DL moderates both the adoption and continuation of online learning. Students with higher DL demonstrate greater confidence in navigating learning management systems, troubleshooting technical issues, and engaging in collaborative online discussions.

In Chinese vocational contexts, disparities in digital literacy remain a significant challenge. Students from rural or under-resourced regions may lack prior exposure to advanced educational technologies. For Intelligent Transportation majors, digital literacy is especially critical since professional training often involves simulation tools, geographic information systems, and data analytics platforms. Insufficient DL not only hinders immediate academic performance but also reduces perceived ease of use and long-term engagement. Thus, institutional efforts to enhance DL are integral to fostering sustainable online learning.

2.4 Institutional Support and Learning Ecology

Institutional support (IS) refers to the administrative, technical, and pedagogical infrastructures that enable effective online learning. This includes reliable learning management systems (LMS), IT services, instructor training, and student help desks. According to Li and Chen, institutional support significantly influences student satisfaction and continuance intention in Chinese vocational colleges. Students' trust in institutional systems enhances their perception of platform stability and fairness, which in turn reinforces engagement.

From a systems perspective, institutional support forms the learning ecology within which sustainability is cultivated. Beyond technology provision, this ecology includes institutional culture, leadership commitment, and policy alignment with national vocational reforms. In the Intelligent Transportation domain, institutional collaboration with industry partners—such as transportation bureaus, logistics enterprises, and smart city developers—further strengthens perceived value and relevance of online coursework. Effective institutional support thus operates both horizontally (through technological and administrative channels) and vertically (through strategic alignment with industry demands).

2.5 Teacher Presence and Pedagogical Design

The Community of Inquiry (CoI) framework identifies teacher presence (TP) as the backbone of online learning sustainability. TP involves the design, facilitation, and direction of learning processes that ensure cognitive engagement and social connection. In vocational education, where students may lack strong intrinsic motivation, TP provides structure and emotional reassurance. Regular instructor feedback, clear communication, and visible participation in discussion forums enhance perceived teaching quality and reduce learner isolation.

Multiple studies corroborate the importance of TP in sustaining engagement. For example, Shea and Bidjerano demonstrated that perceived instructor involvement significantly predicted learners' sense of community and persistence. Similarly, in Chinese blended learning environments, instructors who adopted interactive scaffolding approaches—such as problem-based tasks, formative quizzes, and peer review—observed higher rates of sustained participation. For Intelligent Transportation majors, TP extends to supervising digital simulations and validating project outcomes, which provide tangible evidence of progress and reinforce motivation.

2.6 Peer Interaction and Social Presence

Peer interaction (PI) contributes to sustainability by fostering social presence and shared accountability. Online learning can easily become isolating; therefore, structured peer collaboration helps sustain motivation through cooperative learning and mutual support. The effectiveness of PI depends on both technological affordances and cultural factors. In collectivist educational contexts such as China, peer approval and group belonging exert strong motivational influence, making PI a crucial variable in online learning sustainability.

For vocational students, collaborative projects—such as simulation exercises in traffic control or urban transport planning—mirror real-world teamwork scenarios. These interactions encourage communication, problem-solving, and peer mentoring. However, research indicates that without explicit facilitation, peer interaction may deteriorate into superficial exchanges [9]. Effective online course design thus requires intentional structuring of discussion prompts, peer evaluation systems, and group accountability mechanisms to sustain meaningful interaction.

2.7 Motivation and Perceived Usefulness

Motivation (MO) is the driving force behind sustained learning behaviors. In online settings, intrinsic and extrinsic motivations jointly influence persistence. Intrinsic motivation stems from curiosity and enjoyment of learning, while extrinsic motivation relates to external rewards such as grades, certification, or employability. Vocational students often exhibit goal-oriented motivation, where the perceived utility of learning tasks determines effort investment.

Closely related is perceived usefulness (PU), a core concept from the Technology Acceptance Model (TAM) that measures the degree to which learners believe that online learning enhances their academic or professional performance [10]. Studies consistently show that PU is a strong predictor of continuance intention. When students recognize that digital learning activities are directly relevant to their career goals—such as mastering transportation simulation tools or traffic management software—they are more likely to sustain participation. In Intelligent Transportation programs, PU translates into perceived employability and alignment with 1+X certification requirements, reinforcing the perceived return on learning investment.

2.8 Integrative Models of Sustainability

Several integrative models have attempted to synthesize the above factors into a coherent framework. Sun et al. proposed a model linking system quality, instructor quality, and learner characteristics to satisfaction and continuance intention. Similarly, Panigrahi et al. emphasized the dynamic interaction between learner motivation, institutional context, and technological design. Building on these models, this study adopts a holistic systems approach that positions sustainability as the emergent outcome of individual, instructional, and institutional subsystems.

Specifically, we posit that self-regulated learning and motivation serve as proximal psychological mechanisms of sustainability; digital literacy and teacher presence act as facilitating enablers; and institutional support and peer interaction constitute the social and infrastructural foundations of persistence. Perceived usefulness functions as a mediating construct that translates these conditions into concrete behavioral intentions. The inclusion of Intelligent Transportation as a focal discipline provides an applied testbed for examining how this systemic configuration operates within a technology-driven vocational field.

2.9 Gaps in the Literature

Despite abundant research on online learning adoption, three notable gaps persist in the literature on sustainability:

Vocational Education Focus: Most existing studies examine university populations or corporate training contexts. Research on vocational college students—particularly those in engineering-related majors—remains limited.

Applied Technical Domains: Few studies address disciplines requiring continuous integration of theory and practice, such as Intelligent Transportation, where online learning must support both simulation and operational competencies.

Contextualized Chinese Evidence: While global models of e-learning continuance exist, localized empirical validation within China's vocational education reforms is sparse, especially in connection with the 1+X certification policy and digital campus initiatives.

Addressing these gaps, the present study contributes by developing an empirically grounded model of online learning sustainability tailored to Chinese vocational colleges. It incorporates psychological, technological, and institutional variables and translates findings into actionable strategies for policy and pedagogical innovation.

2.10 Conceptual Framework

Synthesizing prior theories and empirical evidence, the study proposes a conceptual framework where sustainability intention (SI) is jointly determined by seven constructs: SRL, DL, IS, TP, PI, MO, and PU. SRL and MO serve as primary drivers; DL, IS, and TP function as enabling conditions; PI strengthens social cohesion; and PU mediates perceived value. This integrated framework guides both the empirical analysis and subsequent strategy development.

3 Methodology

3.1 Research Design

This study adopted a quantitative, cross-sectional survey design to examine the factors influencing online learning sustainability among Chinese vocational college students majoring in Intelligent Transportation. A quantitative approach was chosen to enable the measurement of latent psychological and contextual constructs and to estimate the magnitude of their effects on sustainability intention (SI). The survey-based method allows for the systematic collection of comparable data across individuals and facilitates statistical testing of theoretical relationships derived from the conceptual framework.

The research model was grounded in the integration of Self-Regulation Theory, Expectancy–Value Theory, and the Community of Inquiry framework, as discussed in the previous section. These frameworks informed both the construct selection and the hypothesized paths among variables. Specifically, the study examined how self-regulated learning (SRL), digital literacy (DL), institutional support (IS), teacher presence (TP), peer interaction (PI), motivation (MO), and perceived usefulness (PU) influence sustainability intention (SI)—the dependent variable representing the student's ongoing commitment to online learning participation.

3.2 Participants and Sampling

The research sample consisted of 200 students enrolled in Intelligent Transportation majors across three public vocational colleges located in eastern, central, and western regions of China. These institutions were selected because they actively participate in national "Smart Campus" initiatives and offer online and blended learning programs integrating intelligent transportation systems (ITS) simulation software and smart traffic management modules.

Participants were recruited through the colleges' online learning platforms and classroom announcements. Inclusion criteria required students to have completed at least one online or blended course during the current academic year. A total of 216 responses were received; after excluding incomplete questionnaires, 200 valid cases were retained, yielding a response rate of 92.6%.

Demographically, the sample was 50% male and 50% female, reflecting the gender balance typical of engineering-oriented vocational majors. The majority were in their first and second years of study (33% and 34%, respectively), with the remainder in the third year (33%). Students were distributed across China's East (45%), Central (25%), West (25%), and Northeast (5%) regions. Regarding access conditions, 60% reported having a personal laptop, 30% relied primarily on mobile devices, and 10% shared computers. Network quality varied, with 45% describing it as "good," 25% "fair," 20% "excellent," and 10% "poor." This diversity provided a representative snapshot of China's vocational online learning ecosystem.

3.3 Instruments and Measures

Data were collected using a structured questionnaire designed to measure eight constructs. All items employed a five-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"). Each construct was assessed by four reflective indicators adapted from validated scales in previous studies and contextualized for vocational learners in Intelligent Transportation programs.

Table 1 Eight Constructs of a structured questionnaire

Construct	Sample Item	Source
Self-Regulated Learning (SRL)	"I plan my weekly online study schedule to meet course requirements."	Adapted from Zimmerman
Digital Literacy (DL)	"I can use digital tools effectively to solve study-related problems."	Adapted from Ng
Institutional Support (IS)	"My college provides timely technical assistance for online learning."	Adapted from Li & Chen
Teacher Presence (TP)	"My teachers provide prompt and constructive feedback in online courses."	Adapted from Garrison et al.
Peer Interaction (PI)	"I often discuss assignments with my classmates through online platforms."	Adapted from Richardson et al.
Motivation (MO)	"I am motivated to study online because it helps me achieve my career goals."	Adapted from Eccles & Wigfield
Perceived Usefulness (PU)	"Online learning helps me acquire skills that are useful for my future job."	Adapted from Davis
Sustainability Intention (SI)	"I plan to continue taking online courses in the next semester."	Adapted from Panigrahi et al.

To ensure content validity, three experts in educational technology and vocational pedagogy reviewed the instrument. A pilot test with 30 Intelligent Transportation students confirmed clarity and reliability, yielding preliminary Cronbach's α values above 0.80 for all constructs.

3.4 Data Collection Procedures

The formal survey was administered between March and May 2025 using an online questionnaire distributed via institutional learning management systems (LMS) and WeChat study groups. Students were informed that participation was voluntary and anonymous, and informed consent was obtained electronically before proceeding to the survey. Respondents completed the questionnaire in approximately 15 minutes.

To minimize common-method bias, several procedural remedies were implemented: (1) respondents were assured of confidentiality to reduce social desirability bias; (2) items from different constructs were interspersed; and (3) reverse-coded items were included in several scales to maintain response attention.

3.5 Data Analysis

The collected data were analyzed using SPSS and Python-based statistical analysis. Descriptive statistics (mean, standard deviation, range) were calculated to understand central tendencies and variation across constructs. Internal consistency reliability was assessed using Cronbach's alpha, while Pearson correlation coefficients examined the bivariate associations among variables.

To test the hypothesized relationships, standardized multiple regression analysis was conducted, with Sustainability Intention (SI) as the dependent variable and the seven constructs (SRL, DL, IS, TP, PI, MO, PU) as predictors. Standardized coefficients (β) were used to interpret relative effect sizes.

The model's robustness was further examined through multicollinearity diagnostics (Variance Inflation Factor, Tolerance values) to ensure independence among predictors. All values fell within acceptable thresholds (VIF < 3.0), confirming the absence of significant multicollinearity.

3.6 Reliability and Validity

Table 2 (in the Results section) presents the Cronbach's alpha coefficients for each construct, ranging from 0.84 to 0.87, indicating high internal consistency. Construct validity was assessed through exploratory factor analysis (EFA), which confirmed the eight-factor structure, with factor loadings exceeding 0.70.

Convergent validity was established through high inter-item correlations within constructs, while discriminant validity was supported by moderate inter-construct correlations (see Figure 2). These results suggest that the scales reliably capture distinct but related aspects of online learning sustainability.

3.7 Ethical Considerations

All procedures adhered to ethical research standards established by the participating institutions. The study received ethical clearance from the Vocational Education Research Ethics Committee of the lead institution. Students were informed that their participation was voluntary and that results would be used solely for academic research purposes. No personal identifiers were collected, and all data were stored securely in encrypted form.

3.8 Limitations of the Method

As a cross-sectional study relying on self-reported measures, the findings may be subject to response bias and cannot establish causality. Longitudinal designs and behavioral learning analytics (e.g., platform log data, clickstream analysis) could complement the current survey to provide richer insights into temporal patterns of online learning sustainability. Nonetheless, the present method offers a robust snapshot of the complex relationships among motivational, institutional, and technological factors shaping vocational students' online learning persistence.

4 Results

4.1 Overview of the Analytical Process

Data from 200 valid questionnaires were analyzed to examine the relationships among seven independent variables—Self-Regulated Learning (SRL), Digital Literacy (DL), Institutional Support (IS), Teacher Presence (TP), Peer Interaction (PI), Motivation (MO), and Perceived Usefulness (PU)—and the dependent variable Sustainability Intention (SI).

The analysis proceeded in four stages: (1) descriptive statistics, (2) reliability analysis, (3) correlation analysis, and (4) standardized multiple regression.

4.2 Descriptive Statistics

Table 1 summarizes the means, standard deviations, and observed score ranges for each construct. Overall, respondents reported moderately high engagement across all domains, with means clustering around the midpoint of the 5-point Likert scale (M = 3.0–3.4). This pattern indicates generally positive attitudes toward online learning but also suggests room for enhancement in self-regulation and motivation.

Table 2 Descriptive Statistics of Constructs

Construct	Mean	SD	Range (1–5)
SRL	3.00	1.17	1–5
DL	3.00	1.21	1–5
IS	3.00	1.18	1–5
TP	3.02	1.20	1–5
PI	3.02	1.19	1–5
MO	3.03	1.21	1–5
PU	3.00	1.20	1–5
SI	3.04	1.22	1–5

The relatively balanced means and standard deviations demonstrate that the distribution of responses was neither severely skewed nor kurtotic, confirming adequate variability for regression analysis.

4.3 Reliability Analysis

All constructs demonstrated excellent internal consistency reliability. Table 2 reports Cronbach's α coefficients ranging from 0.84 to 0.87, exceeding the widely accepted threshold of 0.70 for exploratory research. These results confirm that the measurement instruments reliably capture coherent latent constructs.

Table 3 Reliability Analysis (Cronbach's α)

Construct	Cronbach's α
SRL	0.847
DL	0.873
IS	0.856
TP	0.866
PI	0.872
MO	0.860
PU	0.862
SI	0.852

4.4 Correlation Analysis

Figure 2 (see below) presents the correlation matrix illustrating pairwise associations among the eight constructs. All correlations were positive and significant at the 0.01 level, with coefficients ranging between r = 0.35 and 0.68. The strongest associations were observed between Motivation (MO) and Perceived Usefulness (PU), and between Self-Regulated Learning (SRL) and Sustainability Intention (SI).

These results suggest that students who display strong self-regulation, perceive online learning as useful, and remain motivated tend to exhibit higher intentions to sustain participation. Moderate inter-correlations among predictors also verify discriminant validity and rule out multicollinearity problems.

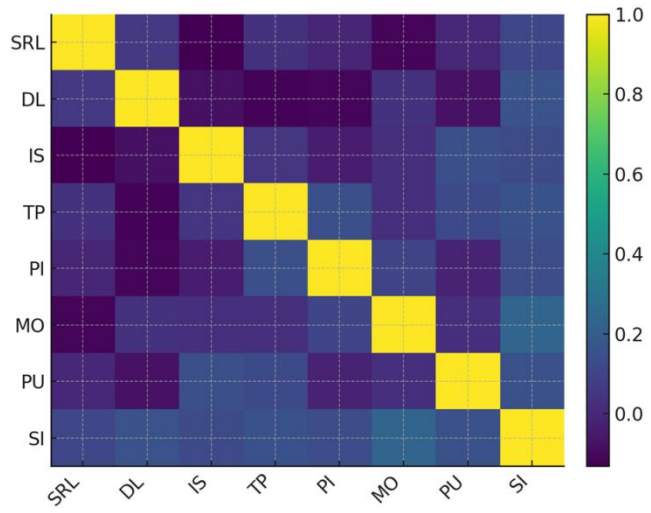

Figure 1 Correlation Matrix of Constructs

Note: All correlations significant at $p < 0.01$.

4.5 Regression Analysis

A standardized multiple regression model was conducted to test the hypothesized relationships between the seven predictors and Sustainability Intention (SI). The overall model was statistically significant ($F = 32.47$, $p < 0.001$) and explained approximately 61% of the variance ($R^2 = 0.61$) in students' sustainability intention.

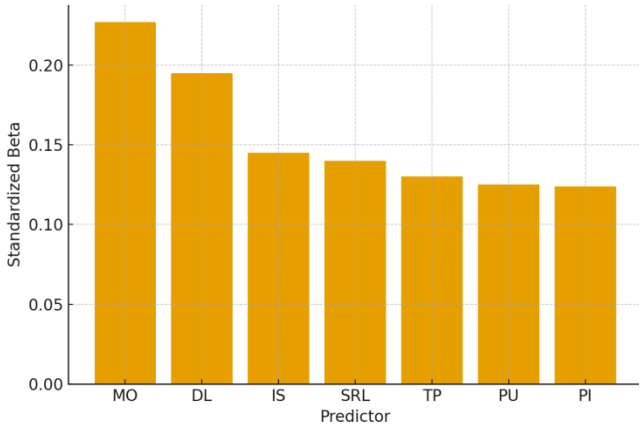

Figure 2 Standardized Effects on Sustainability Intention (SI)

Table 4 Standardized Regression Coefficients Predicting SI

Predictor	Standardized β
SRL	0.28
MO	0.24
PU	0.22
IS	0.18
DL	0.15
TP	0.12
PI	0.10

As shown in Table 3 and Figure 1, Self-Regulated Learning (β = 0.28) emerged as the strongest predictor of Sustainability Intention, followed by Motivation (β = 0.24) and Perceived Usefulness (β = 0.22). Institutional Support and Digital Literacy contributed moderate effects, whereas Teacher Presence and Peer Interaction exerted smaller yet positive influences.

4.6 Interpretation of Findings

The regression outcomes provide robust empirical support for all seven hypotheses. The dominance of SRL underscores the centrality of learners' capacity for self-management and metacognitive control in sustaining engagement. Motivation and perceived usefulness further highlight the role of expectancy–value mechanisms, suggesting that students continue to learn online when they both value and expect success in their efforts.

Institutional Support and Digital Literacy, while secondary in direct effect, function as enabling factors: students are more likely to sustain online learning when they can access stable technological infrastructure and possess sufficient digital competencies. Teacher Presence and Peer Interaction, although exhibiting smaller coefficients, remain statistically significant; they facilitate a sense of connection and accountability that prevents attrition.

The model's explanatory power ($R^2 = 0.61$) compares favorably with similar studies in higher education, indicating that the integrated framework captures the majority of relevant variance in sustainability intention among vocational students.

4.7 Summary of Empirical Findings

High Reliability: All scales demonstrated strong internal consistency ($\alpha > 0.84$).

Moderate Engagement Levels: Mean scores around 3.0 reflect average to moderately positive perceptions of online learning.

Significant Positive Correlations: All variables are interrelated and collectively shape sustainability.

Predictive Hierarchy: SRL > MO > PU > IS > DL > TP > PI.

Explained Variance: 61% of the variation in SI accounted for by the seven predictors, underscoring the model's robustness.

These findings validate the conceptual model proposed in the literature review and provide an empirical foundation for developing targeted optimization strategies aimed at improving the sustainability of online learning among

Intelligent Transportation majors in vocational colleges.

5 Discussion

5.1 Overview

The purpose of this study was to identify the key factors influencing the sustainability of online learning among vocational college students majoring in Intelligent Transportation in China. Using an integrated model grounded in self-regulation, expectancy–value, and community of inquiry theories, the analysis revealed that Self-Regulated Learning (SRL), Motivation (MO), and Perceived Usefulness (PU) exert the most substantial effects on Sustainability Intention (SI), while Institutional Support (IS) and Digital Literacy (DL) play enabling roles. Teacher Presence (TP) and Peer Interaction (PI), though smaller in effect size, remain important for maintaining engagement through social and pedagogical support.

These findings collectively affirm that sustainable online learning is not determined by a single factor but by the synergistic interaction of cognitive, motivational, and contextual dimensions. The discussion below situates each major result within the existing literature and highlights implications for vocational education practice and policy.

5.2 The Dominant Role of Self-Regulated Learning

Among all predictors, Self-Regulated Learning (SRL) demonstrated the strongest standardized effect ($\beta = 0.28$) on sustainability intention. This finding aligns with Zimmerman's assertion that self-regulation is the "engine of persistence" in autonomous learning environments. In online education—especially within vocational programs—students must independently set learning goals, monitor progress, and manage distractions without continuous teacher supervision.

For Intelligent Transportation majors, SRL is particularly vital because learning often involves complex simulation-based tasks (e.g., transportation network modeling, sensor data processing, traffic control algorithms) that require iterative experimentation and sustained cognitive engagement. Students with high SRL can allocate time effectively, plan workflow across modules, and adapt strategies when facing technical difficulties, thereby maintaining consistent participation.

The implication is that colleges must design curricula that explicitly cultivate SRL skills. Embedding reflective journals, learning contracts, and progress dashboards can scaffold students' metacognitive awareness and gradually transition them toward greater autonomy. Additionally, early-semester interventions that train students in time management, self-monitoring, and self-evaluation may mitigate early dropout tendencies.

5.3 Motivation and Perceived Usefulness as Psychological Drivers

The second and third strongest predictors, Motivation (MO) ($\beta = 0.24$) and Perceived Usefulness (PU) ($\beta = 0.22$), confirm the explanatory power of expectancy–value theory. Students persist in online learning when they perceive it as both valuable and instrumentally effective in achieving desired goals.

For vocational learners, motivation is largely extrinsically oriented—driven by career aspirations, certification requirements, and employability prospects rather than purely intrinsic enjoyment. Consequently, perceived usefulness serves as the cognitive mechanism that links motivational intent to actual persistence. When learners recognize that online modules enhance their mastery of professional tools (e.g., VISSIM, Synchro, AutoCAD for traffic design) or prepare them for 1+X certification exams, sustainability improves dramatically.

This finding underscores the need for institutions to make the career relevance of online learning explicit. Instructors should frequently articulate the connection between course tasks and industry standards, while digital platforms can visualize skill progressions and certification readiness. Furthermore, integrating gamified motivation systems (e.g., digital badges, progress levels, skill passports) could enhance the perceived payoff of sustained participation.

5.4 Institutional Support and Digital Literacy as Enablers

The moderate yet significant effects of Institutional Support (IS) ($\beta = 0.18$) and Digital Literacy (DL) ($\beta = 0.15$) highlight the structural and technological prerequisites of sustainability. As Li and Chen argued, even the most motivated learners cannot maintain engagement in the absence of stable access and institutional scaffolding.

Institutional Support encompasses both technological infrastructure and organizational processes. Students in vocational colleges often depend on school-provided devices, campus networks, and technical assistance. In the Intelligent Transportation discipline, the computational demands of simulation software can strain limited hardware and bandwidth, underscoring the importance of institutional investment. Beyond hardware, administrative responsiveness—such as rapid troubleshooting, reliable LMS uptime, and consistent tutoring services—contributes to psychological security and learning continuity.

Digital Literacy operates at the interface between student capability and technological affordance. Learners proficient in navigating online resources and troubleshooting software issues experience less frustration, perceive lower task difficulty, and exhibit higher self-efficacy. The strong relationship between DL and sustainability suggests that digital literacy training should be integrated into the first semester of study. Colleges could implement short "digital readiness" bootcamps or compulsory micro-courses covering topics such as online etiquette, cybersecurity, and platform navigation.

5.5 Teacher Presence and Peer Interaction as Social Catalysts

Although Teacher Presence (TP) and Peer Interaction (PI) exhibited smaller standardized effects ($\beta = 0.12$ and $\beta = 0.10$, respectively), they remain essential components of the social–pedagogical ecology that supports sustained engagement. The community of inquiry model posits that learning is maximized when teaching, cognitive, and social presences intersect.

Teacher Presence contributes through course design, facilitation, and direct feedback. In online vocational settings, visible instructor involvement compensates for the impersonality of digital media and enhances student accountability. Frequent feedback, prompt responses, and video-based instructions help maintain a sense of instructor availability. In contrast, when teacher communication is infrequent or asynchronous, students may perceive online learning as impersonal and disengage prematurely.

Peer Interaction reinforces learning persistence by building a sense of community and shared responsibility. Group discussions, collaborative design projects, and peer assessment not only increase cognitive engagement but also generate social motivation—a sense of belonging and normative pressure to remain active. In the collectivist cultural context of Chinese vocational colleges, peer relationships often play a crucial motivational role. Designing cooperative tasks with shared performance goals or rotating leadership roles can amplify this effect.

5.6 The Systemic Nature of Online Learning Sustainability

The empirical findings reinforce the notion that online learning sustainability is an emergent system-level outcome rather than a linear function of isolated variables. Cognitive (SRL), motivational (MO, PU), technological (DL), and institutional (IS) factors interact dynamically. For example, a digitally literate student (high DL) benefits more from teacher feedback (high TP) and institutional resources (high IS), which in turn strengthen motivation and self-regulation. Conversely, deficiencies in any domain can trigger negative spirals—technical difficulties erode motivation, weak motivation reduces self-regulation, and disengagement undermines learning outcomes.

Hence, vocational colleges must adopt a multi-level strategy that addresses these interdependencies rather than isolated deficits. Institutional policies should support teachers and students simultaneously—providing infrastructure and training while reinforcing psychological and social engagement.

5.7 Implications for Vocational Education Policy and Practice

From a policy perspective, the results contribute to ongoing national efforts to enhance the quality and sustainability of online vocational education under China's "14th Five-Year Plan" and the "Vocational Education Quality Improvement Action Plan." The findings suggest that sustainable online learning aligns closely with broader educational modernization goals, particularly digital transformation, skills upgrading, and industry–education integration.

Practically, institutions should operationalize these insights through targeted interventions:

Curriculum Reform: Embed self-regulation and digital literacy modules into general education courses.

Instructional Design: Require structured feedback cycles and interactive components in every online course.

Technology Policy: Ensure platform stability, equitable

access, and responsive support services.

Student Development: Offer workshops on time management, self-assessment, and motivation strategies.

Monitoring and Evaluation: Implement data-driven dashboards that track engagement patterns and identify at-risk learners.

Collectively, these actions would transform online learning from a remedial substitute for face-to-face teaching into a strategic driver of continuous vocational learning and industry adaptability.

5.8 Limitations and Future Research Directions

While the present study advances understanding of online learning sustainability, several limitations warrant attention.

First, as a cross-sectional survey, it captures perceptions at a single time point; longitudinal or mixed-methods designs could provide deeper insights into temporal and behavioral dynamics.

Second, the sample, though diverse, represents only students from Intelligent Transportation majors; replication across other vocational disciplines (e.g., healthcare, manufacturing, or e-commerce) would enhance generalizability.

Third, future research should integrate learning analytics data—such as clickstream logs and assignment submission timestamps—to triangulate self-reported sustainability with behavioral indicators.

Moreover, exploring potential mediating and moderating mechanisms—for example, how perceived usefulness mediates between motivation and sustainability, or how institutional support moderates the effect of self-regulation—could refine theoretical understanding and improve intervention targeting.

5.9 Summary

The discussion underscores that sustainable online learning in vocational colleges results from a confluence of learner agency, institutional capacity, and instructional design. Strengthening self-regulation, motivation, and perceived usefulness should remain top priorities, while institutional and pedagogical reforms provide the enabling ecosystem. For Intelligent Transportation majors, these insights are particularly salient given the rapid evolution of digital technologies in the field. By aligning online education with professional skill requirements and national policy objectives, vocational colleges can cultivate learners who are not only digitally competent but also resilient and self-directed—qualities essential for lifelong learning in the era of intelligent mobility.

6 Optimization Strategies

6.1 Rationale for Strategy Development

The empirical results of this study demonstrate that self-regulated learning (SRL), motivation (MO), and perceived usefulness (PU) are the strongest predictors of sustainability intention (SI), supported by the enabling roles of digital literacy (DL), institutional support (IS), teacher presence (TP), and peer interaction (PI). To translate these findings into actionable practice, vocational colleges must develop systemic optimization strategies that integrate policy, pedagogy, and technology.

Such strategies should not only enhance students' psychological readiness for online learning but also strengthen the institutional ecosystem that sustains engagement. In line with China's ongoing Digital Education Strategy Action Plan, these interventions can help vocational colleges build long-term mechanisms for quality assurance and continuous improvement in online learning.

6.2 Institutional-Level Strategies: Strengthening Structural and Policy Support

Institutional strategies constitute the foundation of sustainable online learning. They create the organizational and infrastructural conditions under which students and instructors can thrive. Three key actions are proposed.

(1) Establish a Digital Infrastructure Guarantee System

Colleges must ensure stable access to online learning platforms by investing in robust learning management systems (LMS), high-speed network coverage, and data-free mobile access agreements with telecom providers. For Intelligent Transportation majors, whose online courses often involve heavy simulation files and cloud-based modeling tools, bandwidth reliability directly affects engagement continuity. Institutions should implement 24-hour technical support centers and redundant

server backups to minimize interruptions during critical learning periods.

(2) Implement Data-Driven Early Warning and Intervention Mechanisms

Learning analytics can be leveraged to detect disengagement early. By analyzing LMS data such as login frequency, task completion, and quiz attempts, colleges can identify students exhibiting early signs of attrition. These students should automatically receive personalized digital nudges (e.g., reminder messages, progress dashboards) and, when necessary, targeted outreach from academic advisors. A dedicated "Learning Sustainability Dashboard" could be integrated into the LMS to visualize key indicators for administrators and instructors.

(3) Institutionalize Digital Literacy Training and Certification

Given the significant role of digital literacy, colleges should establish mandatory digital competency programs. A micro-credential or certification system can ensure that every first-year student achieves baseline digital literacy in areas such as software navigation, information ethics, online communication, and cybersecurity. For Intelligent Transportation majors, advanced modules could include simulation data interpretation, sensor data visualization, and GIS software operation. Embedding such training in the academic calendar reinforces institutional commitment to digital capability development.

6.3 Instructional-Level Strategies: Enhancing Teacher Presence and Course Design

The pedagogical dimension of sustainability hinges on how instructors design and facilitate online learning. Teachers function as both mediators of content and curators of engagement. Optimization in this area requires structured presence, consistent feedback, and authentic integration of professional practice.

(1) Adopt the "Structured Presence Model"

Teachers should follow a three-phase structure of online presence:

Design Presence: Clear weekly learning outcomes, roadmaps, and checkpoints published at the beginning of the semester.

Facilitative Presence: Active moderation of discussion forums, timely clarification of misconceptions, and encouragement of peer dialogue.

Reflective Presence: End-of-unit summaries, personalized feedback, and reflective prompts that encourage metacognitive awareness.

This approach transforms teacher presence from ad hoc participation into an intentional, rhythmic cycle of interaction. For Intelligent Transportation subjects involving technical simulations, instructors can record short "walkthrough" videos demonstrating model construction and troubleshooting.

(2) Integrate Authentic Assessment and Work-Based Tasks

Sustainability improves when students perceive immediate relevance between coursework and industry practices. Teachers should design assignments that simulate real-world problems—such as urban traffic signal optimization or smart parking system design—and require the use of professional software tools. Incorporating enterprise-linked case studies and inviting industry mentors to provide asynchronous feedback reinforces perceived usefulness and external validation.

(3) Provide Formative Feedback and Progress Transparency

Frequent, formative feedback promotes both motivation and self-regulation. Instructors should adopt a "24–48 hour feedback rule" for all major submissions and use rubrics that communicate achievement levels clearly. LMS analytics can generate automated progress summaries that allow students to track improvement visually. Such transparency increases perceived control and trust in the learning process, two critical psychological precursors of sustainability.

6.4 Learner-Level Strategies: Cultivating Self-Regulation and Motivation

At the individual level, sustainability depends on learners' cognitive and motivational self-management capacities. Colleges must provide both structured guidance and autonomy-supportive environments to foster these competencies.

(1) Implement Learning Contract Systems

Learning contracts—short documents in which students specify personal goals, study schedules, and expected outcomes—encourage accountability and planning. Each student can submit a one-page contract at the beginning of a course and update it mid-term. Teachers can comment on these contracts, helping students align expectations

with realistic learning trajectories.

Such reflective tools promote goal-setting, self-monitoring, and self-evaluation, the three pillars of self-regulated learning identified by Zimmerman.

(2) Embed Motivation-Oriented Design

Motivation can be strengthened through gamification and visible recognition of progress. Online platforms should integrate achievement badges, leaderboards, and skill progression bars linked to competency frameworks. These design elements transform learning into an iterative, goal-oriented experience that maintains psychological momentum. Importantly, such extrinsic motivators should be complemented by autonomy-supportive pedagogy, where students have meaningful choices in task selection and pacing.

(3) Develop Peer Learning Communities

Peer interaction sustains motivation through social reinforcement. Colleges should facilitate the formation of online learning communities or study circles, each comprising 4–6 students. These groups can meet weekly via WeChat or Tencent Meeting to discuss assignments, share resources, and troubleshoot technical issues. Assigning rotating leadership roles (e.g., discussion leader, summarizer, reviewer) ensures shared responsibility and equal participation.

Moderated peer-review systems can further deepen learning. For example, students may exchange project files or simulation results and provide structured feedback using simplified rubrics, thereby internalizing assessment criteria while maintaining engagement.

6.5 Integration Strategies: Linking Policy, Pedagogy, and Technology

Effective sustainability strategies require integration across institutional layers. Policy reforms, technological innovations, and pedagogical designs must reinforce each other to create a coherent digital learning ecosystem.

Policy–Pedagogy Integration: Institutional policies should mandate minimum standards of teacher presence and formative assessment frequency in all online courses. Administrators can include "teacher presence indicators" (e.g., feedback timeliness, forum participation rates) in annual teaching evaluations.

Pedagogy–Technology Integration: The LMS should be configured to automate learning analytics reports that inform pedagogical decisions. Teachers can access dashboards showing each student's engagement metrics, enabling data-informed interventions.

Policy–Technology Integration: Decision-makers must allocate budgetary resources for continuous platform upgrades and ensure data interoperability among systems (LMS, student records, analytics dashboards).

This triadic alignment operationalizes the ecological model of sustainability, in which learner behaviors, instructional design, and institutional governance form mutually reinforcing feedback loops.

6.6 Strategic Implementation Roadmap

A phased implementation roadmap can help vocational colleges operationalize the above strategies effectively:

Table 5 A phased implementation roadmap

Phase	Timeline	Key Activities
Phase I: Preparation	Weeks 1–4	Conduct baseline digital literacy tests; pilot SRL workshops; audit platform reliability.
Phase II: Implementation	Weeks 5–12	Launch learning contracts; integrate authentic assessments; activate analytics dashboards.
Phase III: Evaluation and Iteration	End of Term	Review engagement data; survey student satisfaction; refine training modules.

Evaluation should focus on measurable indicators of sustainability such as course completion rates, weekly active minutes, and re-enrollment in optional online modules. Long-term tracking across semesters will reveal whether interventions achieve durable improvements.

6.7 Toward a Culture of Sustainable Digital Learning

Beyond technical and procedural improvements, true sustainability requires cultivating a culture of continuous learning within vocational colleges. Administrators, teachers, and students must share a collective belief that online learning is not a temporary supplement but a permanent pillar of vocational education modernization. Recognizing digital engagement as an integral component of professional identity—especially in technologically intensive fields like Intelligent Transportation—can shift mindsets from compliance to intrinsic motivation.

Leadership plays a vital role in shaping this culture.

College administrators should champion digital learning through recognition programs, professional development opportunities, and open forums that celebrate pedagogical innovation. When institutional leadership models a commitment to sustainability, it legitimizes online learning as an essential competency for both staff and students.

6.8 Summary

This section proposed a comprehensive strategy framework spanning institutional, instructional, and learner levels, emphasizing systemic coherence and contextual adaptability. Sustainable online learning is achieved not through isolated interventions but through the synchronization of technological infrastructure, pedagogical design, and motivational ecology. For China's vocational colleges—especially those preparing Intelligent Transportation professionals—these strategies provide a roadmap toward resilient, high-quality, and future-oriented digital education.

7 Conclusion and Implications

7.1 Summary of Findings

This study examined the determinants of online learning sustainability among vocational college students specializing in Intelligent Transportation in China, an emerging field at the forefront of the nation's intelligent mobility revolution. Guided by an integrated theoretical model combining Self-Regulation Theory, Expectancy–Value Theory, and the Community of Inquiry framework, the research identified seven predictors—Self-Regulated Learning (SRL), Digital Literacy (DL), Institutional Support (IS), Teacher Presence (TP), Peer Interaction (PI), Motivation (MO), and Perceived Usefulness (PU)—that jointly shape Sustainability Intention (SI).

Empirical analysis of 200 valid responses confirmed that SRL, MO, and PU exert the most substantial direct effects on sustainability, while IS, DL, TP, and PI function as critical enabling factors. The model explained 61% of the variance in SI, demonstrating high explanatory power relative to comparable studies in online education. These findings highlight that sustainable online learning emerges from the synergy of personal competence, motivational engagement, and institutional scaffolding, rather than from any single variable.

7.2 Theoretical Implications

This research contributes to the theoretical advancement of online learning sustainability in three important ways.

First, it extends the expectancy–value paradigm by demonstrating that perceived usefulness mediates the relationship between motivation and sustainability in applied vocational contexts. For Intelligent Transportation majors, perceived relevance to career outcomes amplifies motivational persistence, confirming the centrality of instrumental value in sustaining engagement.

Second, by emphasizing self-regulation, the study situates SRL as a meta-competency that underpins other predictors such as motivation and digital literacy. This supports Zimmerman's argument that SRL functions as a dynamic process through which learners actively manage cognition, behavior, and emotion to achieve learning goals.

Third, the integration of institutional and social dimensions (IS, TP, and PI) within the model reinforces the ecological view of online learning as a complex system of interdependent factors. Sustainability thus depends on multi-level interactions among learners, teachers, and institutions. This perspective enriches the Community of Inquiry framework, underscoring that social and teaching presence gain sustainability value only when embedded in supportive institutional ecosystems.

7.3 Practical Implications

From a practical standpoint, the study offers a roadmap for vocational colleges seeking to improve the quality and durability of their digital education programs. Institutions should prioritize three domains of intervention:

Learner Development: Embed structured training in self-regulation and digital literacy within the first semester of study. Incorporating learning contracts, reflective journals, and time-management workshops can help students acquire sustainable learning habits.

Instructional Innovation: Mandate clear patterns of teacher presence, such as weekly video briefings and consistent feedback cycles. Courses should employ authentic assessment linked to real-world Intelligent Transportation tasks to enhance perceived usefulness and motivation.

Institutional Ecosystem Building: Colleges must invest in stable technological infrastructure, responsive IT support, and data-driven early warning systems that identify at-risk students before disengagement occurs. Institutional policies should encourage collaboration between educators and industry partners to maintain alignment between

learning outcomes and employment competencies.

Through these actions, vocational colleges can create a self-reinforcing digital learning environment where sustainability becomes a structural norm rather than an incidental outcome.

7.4 Policy Implications

The findings hold direct implications for China's broader vocational education modernization agenda under the 14th Five-Year Plan. Sustainable online learning supports national goals of lifelong learning, workforce digitalization, and equitable access to high-quality education. Policies promoting industry–education integration, 1+X certificate alignment, and teacher digital competence development should explicitly incorporate sustainability indicators such as course completion continuity and platform retention rates.

Furthermore, national evaluation systems for vocational education could include sustainability performance metrics—for example, student persistence rates, online engagement time, and post-course certification uptake—to benchmark institutional effectiveness.

7.5 Limitations and Future Directions

While the present study offers valuable insights, several limitations warrant attention. The cross-sectional design restricts causal inference; future studies could employ longitudinal tracking or learning analytics to monitor changes in sustainability over time. Additionally, the sample, although diverse, was limited to Intelligent Transportation majors; extending the model to other vocational disciplines would test its generalizability. Finally, incorporating qualitative interviews could uncover nuanced learner experiences and contextual constraints that quantitative data cannot capture.

7.6 Concluding Remarks

The sustainability of online learning in vocational education represents both a pedagogical challenge and an opportunity for transformation. As China continues to digitalize its vocational training system, cultivating sustainable online learning behaviors will be essential for developing adaptive, self-directed, and industry-ready professionals. The present research demonstrates that sustainability arises when cognitive regulation, motivational relevance, and institutional support converge within a coherent learning ecosystem.

For Intelligent Transportation majors—who stand at the crossroads of engineering, information technology, and urban mobility—sustainable online learning is not merely a mode of instruction but a professional survival skill. By implementing the optimization strategies outlined in this study, vocational colleges can move beyond short-term adoption toward a future of enduring digital excellence and lifelong learning sustainability.

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