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Explaining Student Digital Literacy Through Virtual Learning Environment Quality: Evidence from a Second-Order PLS-SEM Model

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Abstract

This research analyzes the association between the quality of virtual learning environments and students' digital literacy in higher education. From a hierarchical perspective, virtual learning environment quality was defined as a second-order emergent construct integrating technological usability and accessibility with pedagogical mediation. Similarly, student digital literacy was conceived as a second-order emergent construct encompassing information and digital resource management, digital content production, digital communication, collaboration and citizenship, as well as problem-solving and digital autonomy. The study followed a quantitative, non-experimental and cross-sectional design. Data were obtained from 342 university students enrolled in the 2026-I academic term and examined through partial least squares structural equation modeling, applying a two-stage procedure in ADANCO. First-order constructs were estimated as reflective Mode A consistent variables, whose standardized latent scores served as indicators for second-order Mode B emergent constructs. Findings confirmed significant external weights and adequate collinearity levels across all second-order components. The structural model showed a positive and statistically significant association between virtual learning environment quality and student digital literacy ($\beta = 0.795$, $p < 0.001$), with VLEQ accounting for 63.2% of the variance in SDL within the estimated model. Overall, the results suggest that higher perceived digital literacy is associated not only with platform access, but also with pedagogically mediated environments that support interaction, autonomy, and responsible digital engagement.

Keywords: virtual learning environment; student digital literacy; higher education; pedagogical mediation; PLS-SEM

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1. Introduction

The digital transformation of higher education has evolved from a peripheral process into a structural feature of the contemporary university experience. Virtual learning environments (VLEs)—initially conceived as support spaces for distributing materials and managing academic activities—have evolved into pedagogical ecosystems where digital resources, teacher–student interaction, assessment, collaboration, feedback, and

knowledge production converge. This transformation, however, cannot be interpreted solely as a technological expansion. Various studies have shown that the incorporation of digital platforms into higher education does not, in and of itself, guarantee better learning experiences; their value depends, to a large extent, on the interplay between technological conditions, instructional design, faculty guidance, and active student participation [1,2].

The rapid expansion of virtual and blended learning, especially following the global health crisis, highlighted both the potential and the limitations of technology-mediated learning systems. On the one hand, virtual and blended learning enabled educational continuity, expanded access to resources, and diversified forms of academic interaction. On the other hand, the literature has documented persistent problems related to the quality of instructional design, limited interaction, unequal adoption of digital tools, and excessive reliance on platforms conceived as repositories rather than as meaningful learning environments [3,4]. In this context, the quality of the virtual learning environment should be understood as a multidimensional construct that integrates technical and pedagogical dimensions, rather than simply as a perception of ease of use or technological availability. In the Peruvian university context, remote education during the pandemic was also associated with tensions in the student experience, including academic stress [5].

From this perspective, research on the success and effectiveness of e-learning has highlighted that student outcomes are associated with multiple factors in the digital environment. Cidral et al. [6] demonstrated that the quality of the information, the quality of the system, the instructor's attitude, the diversity of assessment methods, and perceived interaction help explain satisfaction, usage, and the individual impact of e-learning. In a similar vein, Al-Fraihat et al. [7] argued that the success of e-learning systems depends on the interaction between technical, human, pedagogical, and service-related factors. Likewise, Kintu et al. [8] showed that the design characteristics of blended learning, together with student variables such as attitude and self-regulation, predict significant outcomes in the learning experience. Taken together, these findings suggest that the quality of a blended learning environment cannot be reduced to the technical stability of the platform but must also incorporate the way in which that platform organizes, supports, and enhances learning.

At the same time, student digital literacy has established itself as a core competency for academic participation in virtual environments. Far from being limited to the instrumental use of devices or applications, digital literacy encompasses the ability to access, evaluate, manage, create, and communicate information using digital technologies, as well as to solve problems, collaborate, and act critically and responsibly in technology-mediated spaces. van Laar et al. [9] identified that contemporary digital skills include technical, informational, communicative, collaborative, creative, critical, and problem-solving dimensions. In addition, Ng [10] proposed understanding digital literacy as a multidimensional competency that integrates technical, cognitive, and socio-emotional dimensions. These approaches are particularly relevant in higher education, where students not only consume digital information but must also produce content, engage in academic interactions, make informed decisions, and manage their learning on complex platforms.

However, the everyday presence of digital technologies in students' lives does not necessarily imply a solid mastery of academic digital skills. The literature has challenged the notion that college students, simply because they belong to generations familiar with technology, automatically possess advanced digital skills. Porat [11] found a significant gap between students' perceptions of their digital competencies and their actual performance on digital tasks. This finding is relevant because it shows that technological self-confidence can mask limitations in the critical evaluation of information, content production, responsible digital interaction, or independent problem-solving. Consequently, the development of

students' digital literacy requires specific institutional and pedagogical conditions, not just frequent exposure to devices or platforms.

The relationship between digital experience, literacy, and online learning has also been examined through explanatory models focused on self-efficacy, engagement, and student participation. Prior et al. [12] found that attitudes toward online learning and digital literacy contribute to self-efficacy, which, in turn, is related to interactive behaviors in learning management systems. More recently, Getenet et al. [13] demonstrated that attitudes toward technology, digital literacy, and self-efficacy influence various dimensions of student engagement in online learning environments. These results suggest that digital literacy does not function as an isolated skill, but rather as a situated capacity that is activated and strengthened within digital educational experiences that offer opportunities for interaction, support, autonomy, and academic production.

Despite these advances, a gap remains in the literature. Much of the research has examined—separately—the quality of e-learning, satisfaction with virtual environments, technological self-efficacy, or digital literacy. However, more empirical evidence is needed on how the quality of the virtual learning environment—conceived as a higher-order construct that integrates technological usability and pedagogical mediation—is associated with student digital literacy, which is also understood as a multidimensional construct encompassing information management, content creation, communication, collaboration, digital citizenship, and autonomous problem-solving. This approach is relevant because it moves beyond fragmented models that analyze isolated dimensions and proposes a more integrated understanding of the relationship between the digital environment, the pedagogical experience, and student competencies.

In this study, the quality of the virtual learning environment is conceptualized as a hierarchical construct composed of two first-order dimensions: the usability and technological accessibility of the VLE, and the pedagogical mediation of the virtual environment. The first dimension refers to the ease of access, navigation, and use of the platform; the second, on the other hand, refers to the way in which the environment organizes activities, facilitates interaction, provides feedback, and supports learning processes. Student digital literacy, for its part, is conceived as a multidimensional construct composed of four dimensions: management of information and digital resources; creation of digital content; communication, collaboration, and digital citizenship; and problem-solving and digital autonomy. This structure addresses the need to analyze digital competencies as complex configurations, rather than as homogeneous or merely technical attributes.

Consequently, the objective of this article is to analyze the statistical association between the quality of the virtual learning environment and student digital literacy in higher education using a hierarchical structural equation model. The study argues that higher perceived quality of the virtual learning environment—supported by both adequate technological conditions and effective pedagogical mediation—is associated with higher levels of self-reported student digital literacy.

The recent post-pandemic literature reinforces the need to examine virtual learning environments and student digital literacy from an integrated perspective. Rather than treating platform access, digital competence, and pedagogical interaction as separate issues, current research suggests that online higher education should be analyzed through the relationship between technological conditions, instructional design, institutional support, and students' academic use of digital tools [14–17]. Accordingly, this study contributes by proposing a hierarchical model in which virtual learning environment quality and student digital literacy are examined as multidimensional constructs within the same empirical framework.

2. Theoretical Background

2.1. Quality of the Virtual Learning Environment

The quality of the virtual learning environment is a complex construct that cannot be reduced to the technical availability of a platform or the ease of access to digital content. In higher education, virtual environments function as spaces for academic mediation where technological infrastructure, instructional design, teacher–student interaction, learning materials, feedback, and institutional support converge. Therefore, their quality must be understood from a multidimensional perspective, in which technological and pedagogical conditions work together to support meaningful learning experiences.

The literature on e-learning has shown that student satisfaction and retention depend on factors that go beyond the technological dimension. Sun et al. [18], in an empirical study on satisfaction with e-learning, identified that students' computer anxiety, the instructor's attitude toward e-learning, course flexibility, course quality, perceived usefulness, ease of use, and the diversity of assessments influence learner satisfaction. This finding is significant because it shifts the focus from the platform as a technical tool to the educational experience that the platform facilitates. Similarly, Liaw [19] demonstrated that perceived satisfaction, behavioral intention, and learning effectiveness in systems such as Blackboard are associated with perceptions of utility, self-efficacy, and interaction conditions. Thus, the quality of the VLE emerges from the relationship between the system, the user, the content, and pedagogical mediation.

From the perspective of digital educational service quality, Pham et al. [20] proposed that the overall quality of e-learning is shaped by dimensions such as system quality, instructor and material quality, and administrative support quality. Their findings showed that these dimensions contribute differently to the overall quality of the service and that this quality is positively correlated with student satisfaction and loyalty. This evidence supports the idea that the VLE should not be evaluated solely on its technical performance but also on how it integrates resources, guidance, communication, and academic support.

In the university context, perceptions of usefulness and ease of use have also been linked to satisfaction and persistence in online courses. Joo et al. [21] found that perceived presence, usefulness, and ease of use of digital tools predict student satisfaction and persistence at online universities. This finding supports the argument that technological usability is necessary but not sufficient: a virtual environment may be accessible and functional, but its educational value depends on its ability to promote interaction, pedagogical presence, and academic continuity.

Pedagogical mediation takes on special significance in this context. Caskurlu et al. [22], through a meta-analysis, demonstrated that instructor presence is positively associated with student satisfaction and perceived learning. Similarly, Richardson et al. [23] found that social presence is associated with satisfaction and learning in online environments. These results allow us to interpret the VLE as a socio-educational space, not merely as a technological interface. Consequently, the quality of the virtual environment depends on its ability to foster guidance, interaction, support, a sense of community, and academic engagement.

Recent reviews on online and e-learning quality in higher education have further clarified that virtual learning environment quality is not determined by technological infrastructure alone. A meta-review of online higher education identified course structure, authentic learning activities, high-quality online interaction, meaningful assessment, student self-regulation, teacher online competence, professional development, institutional vision, technological infrastructure, and support structures as key factors for effective online education [15]. Similarly, recent systematic reviews of e-learning in higher education highlight that learning management systems provide valuable tools for organizing content, assessment, and communication, but their effectiveness depends on the extent to

which they support interaction, engagement, accessibility, and pedagogically meaningful learning activities [16,17]. Thus, the VLE should be interpreted as a multidimensional environment in which technological usability and pedagogical mediation operate jointly rather than independently.

Based on this review, the quality of the virtual learning environment can be conceptualized as a higher-order construct composed of two main dimensions. The first is technological usability and accessibility, which refers to the ease of access, navigation, availability, and operation of the platform. The second is pedagogical mediation, which is linked to the design of activities, feedback, interaction, the clarity of resources, and teacher support. This distinction is relevant because it allows us to recognize that the quality of the VLE is not limited to the digital infrastructure but is fully realized when technology is integrated with intentional pedagogical practice.

2.2. Student Digital Literacy

Student digital literacy is a multidimensional competency that integrates technical, cognitive, informational, communicative, creative, and socio-educational skills. In contemporary higher education, students must not only access digital resources but also evaluate information, produce content, communicate academically, collaborate in digital environments, solve problems, and act responsibly in technology-mediated spaces. Therefore, digital literacy cannot be understood as mere familiarity with devices, platforms, or applications. This responsible participation has become especially relevant with the rise of generative artificial intelligence, which has introduced new challenges for academic integrity in higher education [24].

Zhao et al. [25], in a systematic review of digital competence in higher education, noted that research in this field is characterized by conceptual diversity, a variety of dimensions, and methodological heterogeneity. This situation demonstrates that digital competence is not a one-dimensional construct, but rather a broad category that encompasses different levels of performance and various areas of academic application. In this regard, student digital literacy should be understood as a set of situated capabilities, the development of which depends both on the student's individual characteristics and on the educational opportunities offered by the university context.

The literature has also highlighted that digital literacy is linked to the processes of searching for, evaluating, and managing information. Greene et al. [26] demonstrated that critical components of digital literacy—such as planning search strategies, monitoring the process, and evaluating information—are related to learning. This finding is important because it emphasizes the metacognitive dimension of digital literacy: it is not enough simply to access information; rather, students must be able to decide which information is relevant, reliable, and useful for their academic purposes.

Likewise, technological self-efficacy is a significant factor in the development of digital competencies. Hatlevik et al. [27] found significant relationships between self-efficacy in ICT, learning experiences with computers, and information and computer literacy. From this perspective, digital literacy does not depend solely on observable skills but also on beliefs about competence that influence students' willingness to interact with technologies, solve problems, and engage in complex digital tasks. This is particularly important in virtual learning environments, where autonomy and self-regulation are central to academic performance.

On the other hand, digital literacy includes communicative and collaborative dimensions. Blayone et al. [28], in analyzing the digital readiness of higher education students for collaborative online learning, showed that digital readiness includes technical, communicational, informational, and computational dimensions. This approach helps us understand

that digital literacy is not only an individual skill but also a relational ability: students must interact, collaborate, share resources, reach agreements, and participate responsibly in digital learning communities.

The creation of digital content represents another central dimension. Recent reviews have shown that digital literacy is linked to the ability to produce, transform, and communicate content using digital technologies. Audrin and Audrin [29] identified key factors in the literature on digital literacy, including information literacy, digital learning, ICT, social media, and 21st-century digital skills. Similarly, Tinmaz et al. [30] noted that the literature on digital literacy is organized around themes such as literacies, competencies, skills, and digital thinking. These studies reinforce the need to measure digital literacy as a broad construct, comprising complementary dimensions.

The most recent literature also suggests that digital literacy in higher education must be understood as a dynamic and situated competence rather than as a fixed set of technical skills. Systematic review evidence indicates that digital transformation and digital literacy are closely connected in higher education institutions, especially because universities are expected to prepare students for academic, professional, and social participation in digitally mediated contexts [14]. More recent work has emphasized that pedagogical innovations and institutional strategies are central for embedding digital literacy into curricula and teaching practices [31]. From this perspective, student digital literacy includes not only information search and tool use, but also learner agency, digital communication, content creation, ethical participation, adaptive use of emerging technologies, and autonomous problem-solving [13,31].

Consequently, in this study, student digital literacy is conceptualized as a higher-order construct composed of four first-order dimensions: management of information and digital resources; creation of digital content; communication, collaboration, and digital citizenship; and problem-solving and digital autonomy. This structure allows us to capture the complex nature of digital competence in higher education, avoiding the reduction of this competence to an instrumental measurement focused solely on the technical use of platforms.

2.3. The Relationship Between the Quality of the Virtual Learning Environment and Students' Digital Literacy

The relationship between the quality of the virtual learning environment and student digital literacy can be based on a central premise: digital competencies are not developed solely through exposure to technologies, but rather through educational experiences that are pedagogically designed, mediated, and sustained. A higher-quality virtual learning environment provides the conditions for students to seek information, interact with resources, produce content, collaborate with others, receive feedback, and solve problems using digital tools. Consequently, the virtual environment can function as a learning ecosystem for the development of digital literacy.

From a technological standpoint, an accessible, usable, and stable VLE reduces barriers to entry and makes it easier for students to focus their efforts on more complex academic tasks. Ease of use and perceived usefulness have been associated with satisfaction, persistence, and learning effectiveness in digital environments [19,21]. However, these technical conditions only become fully meaningful when integrated with pedagogical practices that guide the use of technology toward learning objectives. In other words, a functional platform can foster interaction, but it does not in and of itself guarantee the development of advanced digital competencies.

From a pedagogical perspective, teacher mediation and social presence play a decisive role. Meta-analyses of teacher and social presence have shown that both dimensions are related to satisfaction and learning in online environments [22,23]. This suggests that students are more likely to develop digital competencies when the virtual learning

environment (VLE) provides guidance, structure, interaction, and a sense of community. Digital literacy, therefore, is more likely to be reported at higher levels when virtual activities are not limited to downloading materials or answering questionnaires, but rather promote critical information search, content creation, discussion, collaboration, and problem-solving.

The literature on e-learning quality also supports this relationship. Pham et al. [20] showed that the overall quality of e-learning functions as a higher-order construct composed of technical, pedagogical, and support dimensions, and that it is related to key outcomes in the student experience. Although their study focused on satisfaction and loyalty, their findings support the argument that the quality of the digital environment has significant effects on how students perceive, use, and value learning systems. This logic applies to the development of digital literacy: a higher-quality environment offers more opportunities to practice, integrate, and consolidate digital skills.

Similarly, studies on digital readiness and competence in higher education show that students need learning opportunities to transform their everyday use of technology into academically meaningful skills [25,28]. Familiarity with devices or social media does not necessarily equate to academic digital literacy. For academic digital literacy to develop, students need to engage with tasks that require them to select information, transform it into knowledge, communicate it effectively, create digital products, and solve problems independently. Such tasks depend largely on the quality of the virtual environment's design and facilitation.

Recent empirical and review-based evidence strengthens the theoretical plausibility of the relationship proposed in this study. Getenet et al. [13] found that students' digital literacy and attitudes toward digital technology contribute to self-efficacy, which in turn supports different dimensions of online engagement. This suggests that digital literacy is activated through learning environments that provide opportunities for interaction with the system, instructors, and peers. In the same direction, recent systematic reviews on online learning show that student engagement and performance are influenced by the quality of digital tools, internet access, motivation, interactive resources, discussion forums, multimedia elements, and instructor–student interaction [16]. Therefore, a high-quality VLE can be understood as a set of enabling conditions through which students practice, consolidate, and transfer digital competencies in academic contexts [15,31].

This relationship also helps explain why the quality of the VLE should be conceptualized as a precursor to student digital literacy. If the virtual learning environment offers adequate access, clear navigation, relevant resources, meaningful interaction, feedback, and activities focused on production and problem-solving, then it creates favorable conditions for the development of digital competencies. Conversely, if the VLE functions solely as a repository of materials, its contribution to digital literacy will be limited, even when the platform is technically stable.

2.4. Development of the Hypothesis

The preliminary review suggests that the quality of the virtual learning environment and student digital literacy are conceptually distinct but theoretically related constructs. The quality of the VLE describes the technological and pedagogical conditions that shape the online learning experience; student digital literacy, on the other hand, describes the set of skills that enable students to function critically in academic digital environments. The relationship between these two constructs is based on the fact that higher-quality VLEs offer richer settings for the practice, acquisition, and consolidation of digital competencies.

In this regard, technological usability and accessibility facilitate access to resources, reduce operational barriers, and promote continued student participation. However, it is pedagogical mediation that channels these conditions toward more complex educational

practices: information search and evaluation, content creation, collaboration, responsible communication, and problem-solving. Therefore, the quality of e-learning not only promotes student satisfaction and retention but can also help explain differences in their levels of digital literacy.

Furthermore, the reviewed evidence indicates that digital competencies are multidimensional and require learning contexts that integrate information, communication, collaboration, creation, and critical thinking [26,29,30]. Therefore, a model that links the quality of the virtual environment to students' digital literacy makes it possible to integrate two lines of research that have often been addressed separately: the quality of e-learning systems and the development of digital competencies in higher education.

Consequently, the following hypothesis is formulated:

H1. *The quality of the virtual learning environment is positively and significantly associated with students' digital literacy.*

The review also justifies the hierarchical specification of the model. VLE quality is understood as a second-order construct composed of usability, technological accessibility, and pedagogical mediation, while student digital literacy is conceived as a second-order construct comprising information and digital resource management, digital content creation, communication, collaboration, and digital citizenship, and problem-solving and digital autonomy. This structure allows for a more accurate representation of the multidimensional nature of both phenomena and provides a coherent theoretical basis for their evaluation through structural equation modeling.

3. Materials and Methods

3.1. Research Design

The study adopted a quantitative approach with a non-experimental, cross-sectional, and explanatory-associative design. It was non-experimental because the variables were observed as they manifested in the educational context, without deliberate manipulation by the researchers. It was cross-sectional because the data were collected at a single point in time. The explanatory-associative scope is justified because the central purpose was to analyze the statistical relationship between perceived virtual learning environment quality and students' self-reported digital literacy within a hierarchical PLS-SEM model. Since no out-of-sample predictive assessment was conducted, the term predictive was not used in the strict sense of external predictive performance.

The choice of a quantitative approach using partial least squares structural equation modeling (PLS-SEM) was driven by the multidimensional nature of the model, the interest in estimating statistical associations between multidimensional constructs, and the inclusion of second-order hierarchical variables. PLS-SEM was selected because it is suitable for estimating complex structural models that include hierarchical, formative, composite, or emergent components. In the present study, its use was particularly appropriate because both virtual learning environment quality and student digital literacy were specified as second-order emergent constructs composed of theoretically distinct first-order dimensions. However, given the cross-sectional design and the absence of an out-of-sample predictive assessment, the model was interpreted primarily in explanatory-associative terms rather than as evidence of external predictive performance [32,33].

3.2. Participants and Sample

The sample was obtained through non-probabilistic convenience sampling. Participants were undergraduate students enrolled during the 2026-I academic term in three

Peruvian universities located in Lima. The participating academic programs were Administration, International Business, and Tourism Management. Students were eligible to participate if they were enrolled in one of these programs, had experience using a virtual learning environment for academic activities, and voluntarily agreed to complete the online questionnaire.

Participants were invited through institutional academic channels and/or course-related communication spaces, including teacher-mediated invitations and student groups. No incentives were offered for participation. The invitation included a brief description of the study, the voluntary nature of participation, the estimated completion time, and the informed-consent statement.

Because the sample was limited to students from specific academic programs in Lima, the findings should be interpreted within this empirical context. They cannot be generalized to all university students in Peru or to other disciplinary, institutional, or national settings without further evidence.

The final sample consisted of 342 students from Peruvian universities located in the city of Lima. As shown in Table 1, valid age data were obtained from 341 participants, since one response contained an implausible value and was treated as missing data solely for this descriptive analysis. The mean age was 21.13 years—SD = 3.16—with a range of 18 to 45 years. This value was excluded solely for the descriptive analysis of age and did not affect the sample size used in the model estimation, since the age variable was not part of the constructs analyzed using PLS-SEM. Regarding gender, the group coded as female represented 62.9% of the sample, while the group coded as male represented 37.1%.

Table 1. Demographic data.

Feature	Category	*n*	%
Gender	Female	215	62.9
	Male	127	37.1
Age	M = 21.13; SD = 3.16; range = 18–45	341	—
Academic Program	Administration	185	54.1
	International Business	85	24.9
	Tourism Administration	72	21.1
Academic Cycle	Second cycle	32	9.4
	Third cycle	125	36.5
	Fourth cycle	48	14.0
	Sixth cycle	32	9.4
	Eighth cycle	81	23.7
	Tenth cycle	19	5.6
	Other cycles	5	1.5
Previous educational institution	Public	221	64.6
	Private	121	35.4
Technology equipment used for online classes	Laptop	135	39.5
	Laptop and smartphone	100	29.2
	PC	48	14.0
	PC and smartphone	31	9.1
	Other devices or combinations	28	8.2

In terms of academic programs, the largest proportion of participants belonged to the Professional School of Administration—54.1%—followed by International Business—24.9%—and Tourism Management—21.1%. In terms of academic level, students in the third cycle—36.5%—and eighth cycle—23.7%—predominated. In addition, the majority reported attending a public educational institution—64.6%—while 35.1% attended private institutions. Finally, the technological access profile showed that the most commonly used

device for virtual classes was the laptop—39.5%—followed by a combination of laptop and smartphone—29.2%—which highlights the significant presence of portable devices in the virtual learning experience.

3.3. Variables and Conceptual Model

The research model was structured into two hierarchical levels. At the first level, six first-order constructs were identified: usability and technological accessibility of the virtual learning environment (UTA); pedagogical mediation of the virtual learning environment (EPM); information and digital resource management (IMDR); digital content creation (DCC); communication, collaboration, and digital citizenship (DCOC); and problem-solving and digital autonomy (PSDA), as shown in Table 2.

Table 2. First- and second-order constructs of the model.

Second-Order Construct	First-Order Construct	Denomination	Items
VLEQ	UTA	Usability and Technological Accessibility of VLE	uta1, uta2, uta3, uta4, uta5
VLEQ	EPM	Educational Mediation by VLE	epm1, epm2, epm3, epm4, epm5
SDL	IMDR	Digital Information and Resource Management	imdr1, imdr2, imdr3, imdr4
SDL	DCC	Digital Content Creation	dcc1, dcc2, dcc3
SDL	DCOC	Communication, Collaboration, and Digital Citizenship	dcoc1, dcoc2, dcoc3
SDL	PSDA	Problem Solving and Digital Autonomy	psda1, psda2, psda3

At the second level, two higher-order emergent constructs were formulated. The first was quality of the virtual learning environment (VLEQ), composed of UTA and EPM. The second was student digital literacy (SDL), composed of IMDR, DCC, DCOC, and PSDA. This structure is based on the multidimensional nature of digital competence, which integrates skills in searching, information management, content creation, communication, collaboration, problem-solving, responsible participation, and the critical use of digital technologies. The DigComp 2.2 framework, published by the European Commission, defines digital competence as an integrated set of knowledge, skills, and attitudes that enable individuals to interact critically, safely, and responsibly with digital technologies [34].

3.4. Data Collection Tool

Data were collected using a structured questionnaire designed to measure students' perceptions of virtual learning environment quality and student digital literacy. The instrument was organized according to the first-order constructs of the proposed hierarchical model: usability and technological accessibility of the virtual learning environment (UTA), pedagogical mediation of the virtual environment (EPM), information and digital resource management (IMDR), digital content creation (DCC), communication, collaboration, and digital citizenship (DCOC), and problem-solving and digital autonomy (PSDA).

The development of the questionnaire followed a theory-driven procedure. First, the dimensions and items were formulated based on the conceptual framework of the study and prior literature on virtual learning environments, e-learning quality, digital competence, and student digital literacy. Thus, the items were not developed as isolated statements, but as operational indicators aligned with the theoretical dimensions included in the measurement model.

To support content validity, the preliminary version of the questionnaire was reviewed by three experts with experience in educational technology, virtual learning environments, digital competence, and research methodology. The experts evaluated the clarity, relevance,

coherence, and representativeness of each item in relation to its assigned construct. Their observations were used to refine the wording of several items, reduce ambiguity, and improve the conceptual correspondence between the indicators and the first-order dimensions of the model.

After the expert review, a pilot test was conducted with 30 university students with characteristics like those of the target population. These students were not included in the final analytical sample. The pilot application was used to assess item comprehension, clarity of instructions, response time, and the functioning of the online form. Based on the pilot results, minor wording adjustments were made before the final administration of the questionnaire.

The final instrument used a five-point Likert-type response scale, ranging from 1 = strongly disagree to 5 = strongly agree. Prior to the statistical analysis, the database was reviewed to identify missing values, incomplete responses, and potential inconsistencies. Missing values were handled using case-wise deletion, so that only complete questionnaires were retained for model estimation. The questionnaire administered is presented in the Appendix A.During the expert review and pilot testing, special attention was given to the conceptual alignment between each item and its assigned first-order construct. Nevertheless, some items within the technological usability and accessibility dimension may capture students' broader perception of the virtual learning experience rather than purely technical usability. Some indicators refer not only to access, navigation, and interaction with the platform, but also to perceived learning support, motivation, or engagement with course content. These items were retained because they reflect students' situated experience of the virtual learning environment and showed acceptable empirical behavior; however, this wording may have introduced partial conceptual overlap between perceived virtual learning environment quality and student digital literacy. Therefore, the interpretation of the relationship between VLEQ and SDL should be made cautiously, considering this possible overlap at the measurement level.

3.5. Procedure

Data collection took place from April to May 2026. Participants were informed about the study's objectives, the voluntary nature of their participation, the confidentiality of their responses, and the academic use of the information collected.

The questionnaire was administered via an online form. To reduce potential response bias, neutral instructions were used, socially desirable responses were avoided, and the questionnaire was organized into conceptually distinct sections. In addition, participants' anonymity was guaranteed during data processing [35].

3.6. Data Analysis Strategy

The two-stage hierarchical procedure was implemented as follows. First, the six first-order constructs—UTA, EPM, IMDR, DCC, DCOC, and PSDA—were estimated in ADANCO 2.4.1 as reflective Mode A consistent constructs. After this first-stage estimation, the standardized latent variable scores generated by ADANCO were saved for each participant. These standardized scores represented the empirical position of each respondent on the corresponding first-order construct [36,37].

Second, the standardized latent scores were introduced into a new model as manifest indicators of the second-order constructs. The scores EPM_std and UTA_std were specified as indicators of VLEQ, while IMDR_std, DCC_std, DCOC_std, and PSDA_std were specified as indicators of SDL. At this stage, VLEQ and SDL were modeled as Mode B emergent constructs because their components represented distinct but theoretically related dimensions of a broader multidimensional phenomenon. Collinearity among the

standardized scores was assessed using VIF, and the contribution of each component was evaluated through external weights, external loadings, *t*-values, *p*-values, and 95% bootstrap confidence intervals [33,38].

3.7. Evaluation of the First-Order Measurement Model

The evaluation of first-order constructs considered internal reliability, convergent validity, discriminant validity, and the collinearity of the indicators. Reliability was examined using Dijkstra–Henseler's rho, composite rho, and Cronbach's alpha. Convergent validity was evaluated using average variance extracted (AVE) and the external loadings of the indicators.

Discriminant validity was examined using the HTMT (heterotrait–monotrait ratio) criterion, since the methodological literature has shown that this indicator is more sensitive in detecting problems of discrimination between constructs compared to the Fornell–Larcker criterion and cross-loadings analysis. Values below 0.90 were considered acceptable evidence of empirical discrimination between conceptually related constructs [37].

Although some first-order constructs showed acceptable or near-acceptable internal consistency, the AVE values for EPM, IMDR, DCC, and PSDA were below the conventional threshold of 0.50. Therefore, convergent validity for these dimensions should be interpreted cautiously. These values suggest that a relevant proportion of indicator variance may be attributable to measurement error, limited item precision, short scales, or partial conceptual overlap among indicators.

The decision to retain these constructs was based on their theoretical relevance, acceptable or near-acceptable reliability coefficients, meaningful indicator loadings, absence of problematic collinearity, and acceptable discriminant validity according to HTMT. However, the reflective specification of these first-order dimensions is acknowledged as a methodological approximation. The argument of complementarity is therefore applied primarily to the second-order emergent constructs, where first-order latent scores function as components of broader multidimensional constructs.

3.8. Evaluation of the Second-Order Model

In the second-order model, VLEQ and SDL were evaluated as emergent constructs. Therefore, Cronbach's alpha, composite rho, and AVE were not used as central evaluation criteria, since these indicators are primarily applicable to reflective models. Instead, the analysis focused on the collinearity among components, external weights, external loadings, and the statistical significance of each component [32,33,38].

Collinearity was assessed using variance inflation factors (VIF). External weights were used to determine the relative contribution of each dimension to the higher-order construct, while external loadings were used as supplementary evidence of the absolute contribution of each component. The significance of the weights and the structural path was assessed using bootstrapping with 5000 subsamples, reporting coefficients, standard errors, *t*-values, *p*-values, and 95% confidence intervals [32].

3.9. Structural Model Evaluation Procedure

The structural relationship was assessed using the standardized beta coefficient, the *t*-value, the *p*-value, the bootstrap confidence interval, the coefficient of determination R^2, the adjusted R^2, and the effect size f^2. Given the non-experimental and cross-sectional design, the structural coefficient was interpreted as evidence of statistical association within the estimated model rather than as evidence of causal influence. In addition, because the data were obtained through a single self-report questionnaire, the interpretation of the structural path considered the possible influence of common-method variance and conceptual overlap among perceptual indicators.

3.10. Control of Common Method Bias

Since the data were collected using a single questionnaire, it was deemed necessary to assess the possible presence of common-method bias. To this end, the criterion of complete collinearity was applied using VIF. This procedure has been recommended in PLS-SEM studies as a strategy for identifying whether variance shared by the measurement method could artificially inflate the relationships between constructs [39].

In addition, the questionnaire design incorporated procedural measures aimed at reducing this bias, such as anonymity, neutral instructions, voluntary participation, and the conceptual separation of item blocks [35]. The VIF values obtained were interpreted with reference to a conservative threshold of 3.3, with lower values considered evidence of the absence of severe multicollinearity associated with the common method [39].

3.11. Ethical Considerations

This study was classified as a quantitative, non-experimental, cross-sectional, anonymous, voluntary, and minimal-risk study. According to the official exemption certificate issued by the Academic Coordination of the Graduate Unit of the Faculty of Administrative Sciences, Universidad Nacional Mayor de San Marcos, the study did not require full formal ethical review because it did not involve intervention on participants, clinical procedures, biological sample collection, processing of sensitive data, or collection of personally identifiable information.

Data were collected through an online questionnaire administered to university students. Before completing the questionnaire, participants were informed about the objectives of the study, the academic use of the data, the confidentiality and anonymity of their responses, the voluntary nature of their participation, and their right to withdraw before submitting the form. Participation was permitted only after informed consent had been provided.

The exemption certificate was issued for editorial purposes by the Academic Coordinator of the Graduate Unit, Faculty of Administrative Sciences, Universidad Nacional Mayor de San Marcos.

4. Results

The model was estimated using a two-stage hierarchical approach. In the first stage, first-order constructs associated with the quality of the virtual learning environment and student digital literacy were assessed. Subsequently, the standardized latent scores of these constructs were used as indicators of two emerging second-order constructs: quality of the virtual learning environment (VLEQ) and student digital literacy (SDL). The analysis was conducted using 342 valid observations, with missing values handled using case-wise deletion and bootstrapping with 5000 subsamples. The algorithm converged adequately after seven iterations.

To improve replicability, Supplementary Table S1 reports the descriptive statistics and inter-item correlations for all first-order constructs. Specifically, it includes item means, standard deviations, variances, skewness, kurtosis, and the inter-item correlation matrices for EPM, UTA, IMDR, DCC, DCOC, and PSDA before estimating the second-order hierarchical model.

4.1. Evaluation of First-Order Constructs

Table 3 presents the evaluation of the first-order measurement model. The constructs were estimated as reflective latent variables in Mode A (consistent). In terms of internal consistency, the Dijkstra–Henseler rho, composite rho, and Cronbach's alpha values were

acceptable for most constructs. UTA showed the best psychometric performance, while DCC exhibited marginal values, although close to the 0.70 threshold.

Table 3. Evaluation of first-order constructs.

Construct	Items	rho_A	rho_C	Cronbach's α	AVE	Load Range	Maximum VIF
EPM	5	0.806	0.804	0.802	0.451	0.592–0.702	1.696
UTA	5	0.864	0.864	0.863	0.559	0.728–0.793	2.313
IMDR	4	0.717	0.709	0.702	0.382	0.503–0.670	1.515
DCC	3	0.688	0.688	0.688	0.424	0.635–0.661	1.368
DCOC	3	0.768	0.767	0.766	0.524	0.705–0.756	1.761
PSDA	3	0.739	0.738	0.737	0.485	0.674–0.727	1.610

Note. EPM = pedagogical mediation in the virtual environment; UTA = technological usability and accessibility; IMDR = information and digital resource management; DCC = digital content creation; DCOC = communication, collaboration, and digital citizenship; PSDA = problem-solving and digital autonomy.

As shown in Table 3, the AVE values for EPM, IMDR, DCC, and PSDA were below the conventional threshold of 0.50. This result indicates a limitation in convergent validity at the first-order level and suggests that these dimensions contain a non-negligible proportion of measurement error. Therefore, the measurement results for these constructs should be interpreted with caution. Nevertheless, the constructs were retained because their reliability estimates were acceptable or close to acceptable levels, their indicator loadings were theoretically meaningful, collinearity was not problematic, and discriminant validity was supported through HTMT. Thus, the low AVE values are treated as a measurement limitation rather than as evidence invalidating the overall hierarchical model.

Discriminant validity was assessed using the HTMT criterion. As shown in Table 4, all values were below 0.90. Although some relationships approached the upper limit—particularly EPM–DCC, IMDR–DCC, and EPM–PSDA—the results support an acceptable empirical differentiation between the first-order constructs.

Table 4. Discriminant validity of first-order constructs using HTMT.

Construct	EPM	UTA	IMDR	DCC	DCOC	PSDA
EPM	—	—	—	—	—	—
UTA	0.840	—	—	—	—	—
IMDR	0.831	0.709	—	—	—	—
DCC	0.882	0.697	0.877	—	—	—
DCOC	0.838	0.679	0.789	0.787	—	—
PSDA	0.864	0.703	0.835	0.864	0.784	—

Overall, the first-order measurement model showed acceptable internal consistency for most constructs, no problematic multicollinearity among indicators, and acceptable discriminant validity according to the HTMT criterion. However, the AVE values below 0.50 in EPM, IMDR, DCC, and PSDA indicate limited convergent validity and should be considered when interpreting the robustness of these specific dimensions. The second-order hierarchical model was therefore estimated not as a statistical remedy for low AVE, but because the theoretical model conceptualized VLEQ and SDL as broader multidimensional constructs composed of distinct first-order dimensions.

4.2. Evaluation of the Second-Order Hierarchical Model

In the second stage, the standardized latent scores for EPM and UTA were used as indicators of the emerging construct VLEQ, while IMDR, DCC, DCOC, and PSDA

were used as indicators of the emerging construct SDL. Both constructs were specified as emerging variables in Mode B, due to their composite and multidimensional nature.

With this type of specification, alpha, rho, or AVE should not be interpreted as central evaluation criteria. Instead, the evaluation focuses on the collinearity of the components, the significance of the external weights, the external loadings, and the nomological validity of the structural model.

Table 5 shows that all second-order components had VIF values below 3.3, indicating the absence of problematic multicollinearity. Furthermore, all external weights were positive and statistically significant. In the case of VLEQ, the pedagogical mediation of the virtual environment (EPM) had the highest relative weight, while technological usability (UTA) also contributed significantly. This suggests that the quality of the virtual environment depends primarily on its pedagogical use, rather than being reduced to mere technical accessibility.

Table 5. Evaluation of second-order constructs.

Construct	Component	External Weight	*t*	*p*	95% CI	External Load	VIF
VLEQ	EPM_std	0.787	12.495	<0.001	[0.656, 0.904]	0.980	1.949
VLEQ	UTA_std	0.277	3.809	<0.001	[0.135, 0.420]	0.826	1.949
SDL	IMDR_std	0.220	3.195	0.001	[0.078, 0.351]	0.801	1.947
SDL	DCC_std	0.307	4.569	<0.001	[0.172, 0.437]	0.837	1.965
SDL	DCOC_std	0.349	5.326	<0.001	[0.218, 0.473]	0.840	1.829
SDL	PSDA_std	0.323	3.075	0.002	[0.135, 0.535]	0.849	2.013

Note. VLEQ = quality of the virtual learning environment; SDL = student digital literacy. The confidence intervals correspond to the 95% bootstrap percentile.

As for SDL, all four components were significant. The highest weight corresponded to DCOC, followed by PSDA, DCC, and IMDR. This pattern indicates that student digital literacy is a complex competency, in which communication, collaboration, digital citizenship, autonomy, and content creation play a more prominent role than information management alone.

4.3. Global Fit of the Second-Order Model

Table 6 presents the evaluation of the overall fit of the second-order model. The results were favorable: both the saturated model and the estimated model had an SRMR of 0.0047, a value well below the criterion of 0.08. Furthermore, the dULS and dG values were lower than their respective HI95 and HI99 bootstrap quantiles, which supports the overall adequacy of the model.

Table 6. Global fit of the second-order model.

Model	Index	Value	HI95	HI99	Evaluation
Saturated	SRMR	0.0047	0.0129	0.0161	Appropriate
Saturated	dULS	0.0005	0.0035	0.0054	Appropriate
Saturated	dG	0.0006	0.0046	0.0067	Appropriate
Estimated	SRMR	0.0047	0.0129	0.0161	Appropriate
Estimated	dULS	0.0005	0.0035	0.0054	Appropriate
Estimated	dG	0.0006	0.0046	0.0067	Appropriate

These results show that the second-order hierarchical model has a satisfactory overall fit. Compared to the first level, the second level offers a more parsimonious and statistically robust representation of the relationship between the quality of the virtual learning environment and students' digital literacy.

4.4. Structural Model Evaluation

The main hypothesis of the study posited that virtual learning environment quality is positively and significantly associated with student digital literacy. The results support this hypothesis. The relationship between VLEQ and SDL was positive, strong, and statistically significant, with a β coefficient of 0.795, $t = 35.025$, and $p < 0.001$. The 95% bootstrap confidence interval did not include zero, supporting the statistical stability of the estimated association.

As shown in Table 7 and Figure 1, VLEQ accounted for 63.2% of the variance in SDL within the estimated model, with an adjusted R^2 of 0.631. Furthermore, the f^2 value was very high, with $f^2 = 1.717$. These results suggest that students who reported a more favorable perception of virtual learning environment quality also tended to report higher levels of digital literacy. However, given the cross-sectional and self-reported nature of the data, this relationship should be interpreted as a strong statistical association within the estimated model, not as evidence of causal influence. Moreover, the magnitude of the coefficient may have been influenced, at least in part, by common-method variance and by conceptual proximity among some items related to virtual learning experiences, engagement, and digital competencies.

Table 7. Structural model results.

Path	β	Standard Error	*t*	*p*	95% CI	R^2	Adjusted R^2	f^2
VLEQ → SDL	0.795	0.023	35.025	<0.001	[0.754, 0.843]	0.632	0.631	1.717

Note. VLEQ = quality of the virtual learning environment; SDL = student digital literacy. The values correspond to the standardized coefficient of the structural path and the coefficient of determination for the endogenous construct.

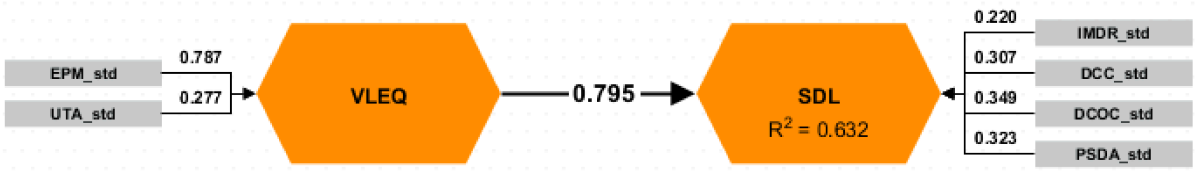


Figure 1. Second-order hierarchical structural model.

4.5. Supplementary Assessment of Common-Method Bias

Since the data were collected using a single questionnaire, we additionally assessed the possible presence of common-method bias through complete collinearity. As shown in Table 8, the VIFs calculated from the standardized latent scores remained below the conservative threshold of 3.3 at both the first and second levels of the model.

Table 8. Full collinearity as common method bias control.

Level	Construct	Full Collinearity VIF	Evaluation
First Level	EPM	3.015	Acceptable
First Level	UTA	2.087	Acceptable
First Level	IMDR	2.035	Acceptable
First Level	DCC	2.130	Acceptable
First Level	DCOC	2.038	Acceptable
First Level	PSDA	2.192	Acceptable
Second level	VLEQ	2.717	Acceptable
Second level	SDL	2.717	Acceptable

The results do not indicate severe common-method bias according to the full collinearity criterion. Nevertheless, this statistical check should be interpreted as complementary

evidence rather than as definitive proof that common-method variance was absent. Since all variables were measured through the same self-report questionnaire and at a single point in time, shared method variance, response consistency, and conceptual overlap among perceptual items may still have contributed to the strength of the observed association between VLEQ and SDL.

Overall, the results of the measurement model and the structural model support the appropriateness of the proposed hierarchical specification. The second-order constructs exhibited adequate compositional specification, significant external weights, the absence of problematic multicollinearity, and a positive and significant structural relationship between VLEQ and SDL.

5. Discussion

The study's results support the relevance of analyzing student digital literacy based on the quality of the virtual learning environment, with the latter understood as a hierarchical construct that integrates technological conditions and pedagogical mediation. The relationship between VLEQ and SDL was positive, strong, and statistically significant, suggesting that students who perceive higher quality in the virtual environment tend to report higher levels of digital literacy. This finding is consistent with the literature, which maintains that learning management systems are associated with more favorable educational outcomes when there is alignment between academic tasks, technological capabilities, and students' learning needs [40]. In this regard, the VLE should not be viewed solely as a platform for accessing content, but rather as an ecosystem for interaction, guidance, and academic production.

A particularly relevant finding is that, within the VLEQ construct, pedagogical mediation had a higher relative weight than technological usability and accessibility. This result suggests that the quality of the virtual environment is associated less with technical availability alone and more with the way the platform is organized pedagogically. Previous evidence has indicated that the evaluation of e-learning systems should consider dimensions such as system quality, service quality, content quality, the student's perspective, instructor attitudes, and institutional support elements [41]. From this perspective, a technically functional platform may prove insufficient if it does not foster meaningful interaction, feedback, or faculty support. This finding also aligns with the "community of inquiry" framework, according to which online educational experiences require the integration of teacher presence, social presence, and cognitive presence to foster deep learning [42].

Regarding student digital literacy, the weights of the components suggest that SDL is not limited to information management or the instrumental mastery of tools. The greater relative contribution of communication, collaboration, and digital citizenship—followed by problem-solving, autonomy, and digital content creation—indicates that digital literacy in higher education is practical, social, and self-regulated in nature. This finding is significant because it challenges the notion that college students, due to their everyday familiarity with technology, automatically possess advanced academic digital competencies. Helsper and Eynon [43] caution that belonging to a particular generation is not sufficient evidence to establish digital proficiency, as differences in experience, scope of use, and learning opportunities may be more significant factors than age. Consequently, the development of digital literacy requires intentional learning experiences and not just frequent exposure to platforms.

The results also show that the virtual environment can contribute to the development of digital competencies when it provides conditions for autonomy, self-regulation, and the completion of complex academic tasks. This interpretation is consistent with the review by Broadbent and Poon [44], who found that strategies such as time management, metacog-

nition, effort regulation, and critical thinking are associated with academic performance in virtual higher education settings. Thus, the quality of the VLE can promote digital literacy to the extent that it structures activities that require students to independently search for, select, produce, communicate, and evaluate information. Conversely, when the virtual environment is limited to serving as a repository, its potential to strengthen digital competencies is reduced.

This finding is consistent with the recent post-pandemic literature showing that the effectiveness of online higher education depends less on the mere availability of digital platforms and more on the pedagogical, interactional, and institutional conditions under which those platforms are used. Recent meta-review evidence indicates that effective online higher education requires clear course structure, authentic activities, high-quality interaction, meaningful assessment, teacher competence, and institutional support [15]. Similarly, recent systematic reviews on digital literacy in higher education emphasize that pedagogical innovation, learner agency, faculty development, assessment practices, and institutional strategies are central to the development of students' digital competencies [14,31]. Accordingly, the present findings reinforce the argument that student digital literacy is not produced automatically by exposure to virtual platforms; rather, it depends on the quality of the pedagogically mediated digital ecosystem [13,16,17].

From a theoretical perspective, this study helps integrate two lines of research that are typically addressed separately: the quality of virtual learning environments and student digital literacy. The hierarchical specification of the model allows both phenomena to be represented as multidimensional constructs and prevents them from being reduced to isolated indicators. This contribution is methodologically relevant because the literature on digital competencies has shown that these competencies depend on individual, pedagogical, and institutional factors, and not solely on access to technology [45]. Therefore, the VLEQ $\rightarrow$ SDL model offers a parsimonious and empirically sound explanation of how conditions in the virtual environment may be associated with the development of digital skills among college students.

In practical terms, the results suggest that universities should prioritize the pedagogical quality of VLE use over investment in technological infrastructure alone. Although accessibility, stability, and ease of navigation are necessary conditions, the most significant educational contribution appears to be related to teacher guidance, the clarity of activities, feedback, interaction, and an emphasis on creating meaningful digital products. This implication is consistent with reviews of blended learning, which identify recurring challenges related to infrastructure, instructional design, interaction, faculty preparation, and student self-regulation [46]. Consequently, institutions should strengthen digital teacher training programs, redesign virtual activities to focus on creation and collaboration, and incorporate criteria for digital citizenship and problem-solving into the everyday use of platforms.

However, caution is required when interpreting these findings. First, because the study used a cross-sectional and non-experimental design, the relationship between VLEQ and SDL cannot be interpreted causally. The coefficient indicates that perceived virtual learning environment quality was strongly associated with self-reported student digital literacy within the estimated model. Second, all data were collected through self-report measures, which may have introduced common-method variance, social desirability, or response consistency effects. Third, some items may show conceptual proximity, particularly those referring to virtual learning experiences, engagement, perceived learning support, and digital competencies. This overlap may have contributed to the magnitude of the observed association. Therefore, the results should be interpreted as evidence of a strong relationship between related perceptual constructs in the analyzed sample, rather than as evidence that virtual learning environment quality directly produces higher digital literacy.

A further measurement limitation concerns the low AVE values observed in EPM, IMDR, DCC, and PSDA. These values suggest that the indicators of these first-order constructs captured less shared variance than expected under a reflective specification, which may reflect measurement error, short item scales, heterogeneous wording, or partial conceptual overlap among dimensions. Consequently, the results associated with these specific dimensions should be interpreted cautiously. Future studies should refine the instrument by increasing the number of theoretically precise items, conducting cognitive interviews with students, applying expert-based content-validity procedures with quantitative indices, and testing the revised scales in independent samples. In addition, alternative measurement specifications, including reflective, composite, and hybrid hierarchical models, should be compared to determine the most appropriate representation of these constructs.

In summary, the study suggests that students' digital literacy does not arise spontaneously from the use of platforms, but rather from the quality of the pedagogical-technological ecosystem in which academic activities take place. The evidence obtained supports the need to conceive of the VLE as a comprehensive learning space, capable of promoting not only access to resources but also interaction, content creation, collaboration, digital citizenship, and autonomy. This conclusion reinforces the importance of designing virtual environments focused on learning and not solely on the administrative management of content.

6. Conclusions

This study analyzed the relationship between the quality of the virtual learning environment and student digital literacy in higher education using a hierarchical structural equation model. The results support the relevance of conceptualizing both phenomena as multidimensional constructs: the quality of the VLE, comprising technological usability and accessibility as well as pedagogical mediation; and student digital literacy, comprising digital information and resource management, digital content creation, communication, collaboration, and digital citizenship, and problem-solving and digital autonomy.

The main finding indicates that perceived virtual learning environment quality was positively and significantly associated with self-reported student digital literacy. This suggests that, in the analyzed sample, higher levels of reported digital literacy were related not only to access to technological platforms or resources, but also to students' perceptions of the pedagogical quality of the virtual ecosystem. Within the VLEQ construct, pedagogical mediation showed a relatively greater weight than technological usability, suggesting that students' evaluation of virtual environments is closely linked to the way activities are organized, interaction is promoted, feedback is provided, and learning is guided.

Likewise, students' digital literacy was found to encompass a broad range of skills, with communication, collaboration, and digital citizenship standing out, along with problem-solving and digital autonomy. This result leads to the conclusion that university digital literacy should not be reduced to instrumental or informational skills, but rather should be understood as a complex, situated, and socially mediated academic competency linked to responsible participation, content production, digital interaction, and the ability to complete tasks in technology-mediated environments.

From a methodological standpoint, the second-order hierarchical model provided a parsimonious and statistically robust representation of the relationship between VLEQ and SDL. Specifying the higher-order constructs as emergent variables allowed for a more appropriate representation of the compositional nature of both phenomena, avoiding an overly restrictive interpretation of the dimensions as homogeneous and interchangeable factors.

In practical terms, the results suggest that institutions of higher education should focus their digital transformation strategies not only on improving technological infras-

tructure but also on strengthening pedagogical mediation in virtual environments. This involves designing activities that promote critical information seeking, content creation, collaboration, digital citizenship, autonomy, and problem-solving.

Finally, the findings should be interpreted in light of the cross-sectional design and the use of self-reports. Future research could expand the model through longitudinal designs, measures of digital performance, multigroup analyses, and out-of-sample predictive evaluations. Even with these limitations, the study provides relevant empirical evidence for understanding how the pedagogical and technological quality of virtual environments can contribute to the development of students' digital literacy in higher education.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/soc16090291/s1, Table S1: Descriptive statistics and inter-item correlations for first-order constructs.

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Institutional Review Board Statement: This study was classified as a quantitative, non-experimental, cross-sectional, anonymous, voluntary, and minimal-risk study. According to the official exemption certificate issued by the Academic Coordination of the Graduate Unit of the Faculty of Administrative Sciences, Universidad Nacional Mayor de San Marcos, the study did not require full formal ethical review because it did not involve intervention on participants, clinical procedures, biological sample collection, processing of sensitive data, or collection of personally identifiable information. Data were collected through an online questionnaire administered to university students. Before completing the questionnaire, participants were informed about the objectives of the study, the academic use of the data, the confidentiality and anonymity of their responses, the voluntary nature of their participation, and their right to withdraw before submitting the form. Participation was permitted only after informed consent had been provided.

Informed Consent Statement: Informed consent was obtained from all participants before they completed the online questionnaire. Participants were informed about the objectives of the study, the academic use of the data, the confidentiality and anonymity of their responses, the voluntary nature of their participation, and their right to withdraw before submitting the form.

Data Availability Statement: The data supporting the findings of this study may be requested from the corresponding author, upon reasonable request and in accordance with the confidentiality and anonymity criteria established for the research.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

The questionnaire was originally administered in Spanish. For transparency and reproducibility, the original Spanish wording of the retained items is presented together with an English translation. The items are organized according to the first-order constructs used in the hierarchical PLS-SEM model.

Survey Instrument Higher-Order Construct	First-Order Construct	Item Code	Original Item in Spanish	English Translation
VLEQ	UTA—Usabilidad y accesibilidad tecnológica del EVA	uta1	Reconozco que Google Classroom es un buen entorno virtual de aprendizaje que mejora mi aprendizaje.	I recognize that Google Classroom is a good virtual learning environment that improves my learning.
VLEQ	UTA—Usabilidad y accesibilidad tecnológica del EVA	uta2	Utilizo los materiales y el contenido de la asignatura en el aula virtual de aprendizaje (Google Classroom) y contribuyen a mi aprendizaje, que sea más comprometido y motivador.	I use the course materials and content available in the virtual learning environment (Google Classroom), and they contribute to making my learning more engaging and motivating.
VLEQ	UTA—Usabilidad y accesibilidad tecnológica del EVA	uta3	Accedo al Entorno Virtual de Aprendizaje (Google Classroom) y reviso la información académica como la agenda, materiales, videos, artículos científicos y páginas web.	I access the Virtual Learning Environment (Google Classroom) and review academic information such as the agenda, materials, videos, scientific articles, and websites.
VLEQ	UTA—Usabilidad y accesibilidad tecnológica del EVA	uta4	Interactúo con facilidad en el Entorno Virtual de Aprendizaje (Google Classroom), ya que se encuentra actualizado.	I interact easily with the Virtual Learning Environment (Google Classroom) because it is up to date.
VLEQ	UTA—Usabilidad y accesibilidad tecnológica del EVA	uta5	Identifico las herramientas y recursos de aprendizaje que incluye el Entorno Virtual de Aprendizaje (Google Classroom), y facilitan mi compromiso con el contenido curricular.	I identify the learning tools and resources included in the Virtual Learning Environment (Google Classroom), and they facilitate my engagement with the course content.
VLEQ	EPM—Mediación pedagógica del EVA	epm1	Identifico el enfoque, competencias y capacidades, así como el enfoque del aula invertida, constructivismo social y conectivista del entorno virtual de aprendizaje, en el sílabo de la asignatura.	I identify the approach, competencies, and capacities, as well as the flipped classroom, social constructivist, and connectivist approaches of the virtual learning environment in the course syllabus.
VLEQ	EPM—Mediación pedagógica del EVA	epm2	Desarrollo las actividades de aprendizaje asíncronas que contribuyen al logro de aprendizaje y desarrollo de la capacidad propuesta.	I complete asynchronous learning activities that contribute to learning achievement and the development of the proposed capacity.
VLEQ	EPM—Mediación pedagógica del EVA	epm3	Considero lo aprendido a través de las actividades de aprendizaje compartidas en el aula virtual, útil e importante para el futuro.	I consider what I have learned through the learning activities shared in the virtual classroom to be useful and important for the future.
VLEQ	EPM—Mediación pedagógica del EVA	epm4	Tengo la capacidad de autoevaluarme oportunamente el cumplimiento de capacidades parciales establecidas en el sílabo.	I am able to self-assess, in a timely manner, my achievement of the partial capacities established in the syllabus.

Survey Instrument Higher-Order Construct	First-Order Construct	Item Code	Original Item in Spanish	English Translation
VLEQ	EPM—Mediación pedagógica del EVA	epm5	Actúo con predisposición a nuevas situaciones de aprendizaje en entornos virtuales de aprendizaje (Google Classroom, entre otros).	I am open to new learning situations in virtual learning environments, such as Google Classroom and others.
SDL	IMDR—Gestión de información y recursos digitales	imdr1	Gestiono y sistematizo información disponible en el aula virtual y entornos virtuales de aprendizaje para desarrollar las actividades académicas de la asignatura.	I manage and systematize information available in the virtual classroom and virtual learning environments to complete the academic activities of the course.
SDL	IMDR—Gestión de información y recursos digitales	imdr2	Analizo, organizo y utilizo estrategias en el aula virtual y entornos virtuales para la búsqueda, localización y selección de información científica en distintos soportes o formatos (texto, video, audio).	I analyze, organize, and use strategies in the virtual classroom and virtual environments to search for, locate, and select scientific information in different formats, such as text, video, and audio.
SDL	IMDR—Gestión de información y recursos digitales	imdr3	Utilizo herramientas digitales para guardar, almacenar, gestionar y compartir archivos digitales (p. ej.: Google Drive, Box, Dropbox, OneDrive, Office 365, etc.).	I use digital tools to save, store, manage, and share digital files, such as Google Drive, Box, Dropbox, OneDrive, Office 365, and others.
SDL	IMDR—Gestión de información y recursos digitales	imdr4	Gestiono recursos educativos digitales en el aula virtual de aprendizaje.	I manage digital educational resources in the virtual learning classroom.
SDL	DCC—Creación de contenido digital	dcc1	Utilizo herramientas de la web 2.0 (blog, videos, Canva, podcast, wiki) para el desarrollo de actividades y logro de aprendizajes.	I use Web 2.0 tools, such as blogs, videos, Canva, podcasts, and wikis, to develop activities and achieve learning outcomes.
SDL	DCC—Creación de contenido digital	dcc2	Elaboro recursos educativos, donde utilizo las TIC de manera creativa, apoyando la construcción de mi conocimiento.	I create educational resources using ICT creatively to support the construction of my knowledge.
SDL	DCC—Creación de contenido digital	dcc3	Desarrollo contenido de aprendizaje a través de recursos y aplicaciones educativas digitales en diversos formatos (texto, imágenes, videos, etc.), donde utilizo las TIC de manera creativa para integrar y reelaborar conocimientos.	I develop learning content through digital educational resources and applications in different formats, such as text, images, and videos, using ICT creatively to integrate and rework knowledge.
SDL	DCOC—Comunicación, colaboración y ciudadanía digital	dcoc1	Ejerzo liderazgo y conciencia intercultural para la ciudadanía digital dentro del aula y comunidad virtuales de aprendizaje.	I exercise leadership and intercultural awareness for digital citizenship within the virtual classroom and the virtual learning community.

Survey Instrument Higher-Order Construct	First-Order Construct	Item Code	Original Item in Spanish	English Translation
SDL	DCOC—Comunicación, colaboración y ciudadanía digital	dcoc2	Desarrollo experiencias o investigaciones educativas con mis pares, que puedan aportarme conocimiento y desarrollo de capacidades y competencia de la asignatura.	I develop educational experiences or research with my peers that can contribute to my knowledge and to the development of course-related abilities and competencies.
SDL	DCOC—Comunicación, colaboración y ciudadanía digital	dcoc3	Demuestro responsabilidad y actitud positiva frente al uso de las TIC para apoyar la colaboración, el aprendizaje y la productividad.	I demonstrate responsibility and a positive attitude toward the use of ICT to support collaboration, learning, and productivity.
SDL	PSDA—Solución de problemas y autonomía digital	psda1	Planifico actividades para tomar decisiones informadas de temas de actualidad y resolver problemas reales, atendiendo las actividades académicas.	I plan activities to make informed decisions about current issues and solve real problems while addressing academic activities.
SDL	PSDA—Solución de problemas y autonomía digital	psda2	Identifico necesidades de uso de recursos digitales para el desarrollo de actividades académicas colaborativas con mis pares.	I identify needs for using digital resources to develop collaborative academic activities with my peers.
SDL	PSDA—Solución de problemas y autonomía digital	psda3	Uso tecnologías de forma creativa para identificar, definir y resolver problemas y/o preguntas de investigación.	I use technologies creatively to identify, define, and solve problems and/or research questions.

Note. VLEQ = Virtual Learning Environment Quality; SDL = Student Digital Literacy; UTA = Technological Usability and Accessibility; EPM = Pedagogical Mediation in the Virtual Environment; IMDR = Information and Digital Resource Management; DCC = Digital Content Creation; DCOC = Communication, Collaboration, and Digital Citizenship; PSDA = Problem-Solving and Digital Autonomy.

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