



Modeling online learning effectiveness in regulated-access technical education

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ABSTRACT

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Online and hybrid learning are now part of everyday higher education practice, but their value is more difficult to assess in technical programs where laboratory work, supervised practice, and operational competencies remain central. This issue is particularly important in regulated-access technical education, where practical and laboratory-based training cannot be reduced to a secondary component of the curriculum. Previous studies have examined satisfaction, engagement, motivation, performance, and practical skills in online or virtual laboratory settings, but less is known about how learning conditions shape students' perceived effectiveness of online learning. This study draws on survey data from 401 engineering and technology students enrolled in Moroccan higher education institutions. It examines the relationships between pedagogical methods, online learning resources, academic interaction, students' psychological state, and perceived learning effectiveness. The proposed causal model was tested using Partial Least Squares Structural Equation Modeling (PLS-SEM). The analysis supports all hypothesized relationships. Academic interaction shows the strongest effect on students' psychological state ($\beta = 0.381$, $p < 0.001$), followed by pedagogical methods ($\beta = 0.214$, $p = 0.002$) and online learning resources ($\beta = 0.168$, $p = 0.011$). Students' psychological state also contributes significantly to perceived learning effectiveness ($\beta = 0.463$, $p < 0.001$). The findings indicate that online learning in technical programs gains educational value when digital resources are pedagogically organized, supported by instructor interaction and feedback, and connected to laboratory preparation.

Contribution/Originality: This study contributes to online learning research by using PLS-SEM to model perceived effectiveness in regulated-access technical education. It shows how pedagogical methods, digital learning resources, and academic interaction influence students' psychological state, which shapes perceived effectiveness in practice-oriented and laboratory-based programs.

1. INTRODUCTION

In technical higher education, moving a course online is not simply a matter of changing the medium through which content is delivered. The issue is more demanding. Engineering students learn through concepts, but also through instruments, measurements, constraints, errors, and practical decisions. A digital environment can provide access to documents, videos, simulations, or exercises. It does not necessarily reproduce the conditions in which operational competence is usually developed.

However, in engineering and technology courses, learning outcomes call for the integration of knowledge, practical applications, and experiments conducted within the lab. Indeed, lab learning is key because it serves as the

basis of technical knowledge, practical skills, competency, and understanding of the integration of theory and practice (May, Terkowsky, Varney, & Boehringer, 2023). Nonetheless, relying only on distance learning can become insufficient if practical involvement, actual experimentation, and pedagogical guidance are limited.

Research carried out in recent years concerning online and virtual labs reveals that the use of digital tools can facilitate practical learning through enhanced accessibility, flexibility, repetition, preparation, and conceptualization. Within the scope of mechanical engineering education, online labs have been utilized to facilitate laboratory learning as supplementary tools due to a lack of physical laboratories (Kapilan, Vidhya, & Gao, 2021). Similarly, video recordings of lab experiments and online activities can help students learn and understand technical processes remotely and virtually; yet such methods are used only as a complement to in-lab activities (García-Ros & Alhama, 2023). Finally, systematic literature reveals that combining real-life experiments with online counterparts enhances conceptual understanding compared to focusing on a specific type of experiment if there is coherence between the two forms (Wörner, Kuhn, & Scheiter, 2022).

In Morocco, this issue also has an institutional dimension. At Hassan II University of Casablanca, as at other regulated-access technical institutions, engineering programs consist of selective entry, structured learning paths, practical training, and pedagogical supervision. In cases when laboratory access is limited, students find it hard to perceive how their activity in online settings prepares them for what they should perform during training. The problem is especially noticeable where access to equipment, access time, and supervised practical work are not equal for all students.

Several studies have examined online, virtual, or blended laboratories through outcomes such as satisfaction, engagement, motivation, practical skills, performance, and learning analytics (Elmoazen, Saqr, Khalil, & Wasson, 2023). However, these studies tend to evaluate specific tools or laboratory formats rather than explain how online learning conditions operate together in regulated-access technical education. This paper examines how pedagogical methods, digital learning resources, and academic interaction influence students' psychological state and, through it, perceived online learning effectiveness. The proposed model is tested using PLS-SEM.

2. LITERATURE REVIEW

2.1. *Online Learning Effectiveness in Applied Technical Education*

The effectiveness of online learning has been extensively studied in higher education with a focus on aspects such as satisfaction, usefulness, engagement, system quality, and technology acceptance. In this study, online learning effectiveness is understood as learners' perceived evaluation of the quality, usefulness, and educational value of the online learning experience. From the perspective of this understanding, the Community of Inquiry theory offers strong grounds for the assessment of online learning effectiveness as the result of interaction among teaching presence, cognitive presence, and social presence (Garrison, Anderson, & Archer, 1999). Several empirical studies have assessed online learning effectiveness based on factors such as system quality, information quality, usefulness, learner satisfaction, engagement, and e-learning acceptance (Al-Fraihat, Joy, Masa'deh, & Sinclair, 2020; Alqahtani, Alamri, Sayaf, & Al-Rahmi, 2022; Li & Zhu, 2022; Martin & Bolliger, 2018).

Although all these approaches provide a good foundation for studying the perceptions of students about online learning and their attitude towards it, they do not cover some aspects that become essential in practice-oriented settings. Namely, online learning effectiveness cannot be considered exclusively in terms of platform quality, learner satisfaction, and usefulness in such situations due to the need to apply theoretical knowledge in practice.

2.2. *Online Learning Conditions in Practice-Oriented Technical Education*

Instructional design enhances comprehension and knowledge acquisition through well-organized learning activities, instructions to guide students' work, and the correspondence between digital tasks and educational goals

(Escueta, Nickow, Oreopoulos, & Quan, 2020). For practical and applied training, such correspondence is even more important, since students need to combine theoretical and practical aspects.

Conditions associated with technology refer to digital learning resources available, accessible, and relevant to students' study. Learning management systems, multimedia tools, simulation- and analytics-based software, online exercises, and resources related to laboratory practices help provide students with materials and monitor their performance (Almaiah, Al-Khasawneh, & Althunibat, 2020; Ifenthaler & Yau, 2020). When applied to engineering education, these technologies become particularly useful when they help connect theoretical content with laboratory experimentation. Interactive e-learning environments can assist in overcoming the existing gap between theory and practice by engaging learners in lab tasks via online means (Kiravu et al., 2016). Laboratory demonstrations, practical experimentation, and simulation can all be combined to prepare students for engineering lab work (Chowdhury, Alam, & Mustary, 2019).

Evidence shows that online and remote laboratories are highly helpful regarding accessibility, preparation, opportunities for repeating the processes, and a better understanding of concepts. However, while these resources could be seen as supplements to traditional practices, they should never be used as complete alternatives to supervised laboratory work and hands-on experience in engineering education (Charitopoulos, Rangoussi, & Koulouriotis, 2022; Faulconer & Gruss, 2018). Moreover, systematic evidence shows that using real and virtual laboratories together can contribute to better conceptual understanding than using one type of laboratory practice (Wörner et al., 2022). Mechanical engineering education, for example, uses virtual labs for laboratory learning due to restricted access to traditional laboratories (Kapilan et al., 2021). Laboratory demonstration videos and remote laboratory practices can also prove useful since they help to observe and review technological practices, but cannot completely replace face-to-face labs (García-Ros & Alhama, 2023).

Interactivity plays a significant role in effective online education as well. Interactions of learners with instructors, other students, and the subject matter allow receiving feedback, clarification, enhanced social presence, and maintained involvement (Borup, Graham, West, Archambault, & Spring, 2020; Martin & Bolliger, 2018). In practice-oriented technical programs, interactivity assumes particular importance as learners need to receive continuous assistance in linking theoretical explanations, digital resources, and practical laboratory skills.

2.3. Psychological Factors as a Mediating Mechanism

Motivation, engagement, confidence, self-regulation, and emotional readiness influence the way students respond to pedagogical methods, digital resources, and academic interaction. These dimensions are strongly associated with academic persistence, learning behaviour, and perceived learning effectiveness (Bond, Buntins, Bedenlier, Zawacki-Richter, & Kerres, 2020; Kahu & Nelson, 2018; Schunk & DiBenedetto, 2020).

The self-determination theory provides an excellent framework to understand this process. According to Ryan and Deci (2020), student motivation is maintained in cases where the needs for autonomy, competence, and relatedness are fulfilled. The fulfillment of these needs in the context of online learning is likely affected by factors such as the design of instruction, digital materials, teacher mediation, and teacher/student interactions.

Furthermore, empirical studies have confirmed the mediating effects of psychological processes in online learning. Ramis and Cheong (2024) reported that fulfillment of psychological needs acted as an effective mediator between cognitive, social, and teaching presence and autonomous motivation in online contexts. It suggests that the psychological state of students serves as an intermediary factor between other processes and their learning experience.

In practice-oriented technical education, this mediating role becomes particularly relevant. Limited access to laboratories, reduced face-to-face supervision, and uncertainty about practical tasks may weaken students' motivation, confidence, and readiness to engage in learning. Accordingly, the present study conceptualizes students' psychological

state as a mediating mechanism through which pedagogical, technological, and interactional conditions shape perceived online learning effectiveness.

2.4. Regulated-Access Technical Education and Research Gap

Research related to online learning and virtual laboratories provides important insights into measures of satisfaction, engagement, motivation, conceptual knowledge, practical skills, performance, and learning analytics. However, research in this area lacks theoretical integration, as it focuses either on common e-learning indicators or specific laboratory applications (Elmoazen et al., 2023; May et al., 2023; Wörner et al., 2022).

Less attention has been given to how online learning environments operate through psychological processes to shape perceived effectiveness in regulated-access technical education. It is worth noting that these courses depend on instructional facilitation, academic discussion, and learner motivation to take up practical tasks.

3. HYPOTHESES DEVELOPMENT

Building on this literature, the present study proposes that online learning conditions influence perceived effectiveness through students' psychological state, which is conceptualized as the mediating mechanism of the model.

3.1. Pedagogical Methods and Students' Psychological State

Pedagogical methods shape how online learning activities are organized, explained, monitored, and connected with practical work. In practice-oriented teaching, pedagogically organized lessons can help improve the confidence and knowledge of students as well as prepare them for further participation in practical activities. Based on self-determination theory, such approaches can foster perceived competence and relatedness, two necessary elements for engagement in studies (Ryan & Deci, 2020). Existing literature supports the role of pedagogically appropriate support provided by instructors in fostering student satisfaction and motivation (Kuo, Walker, Schroder, & Belland, 2014; Martin, Wang, & Sadaf, 2018).

H₁: Pedagogical methods positively impact students' psychological state when studying online in practice-oriented technical education.

3.2. Digital Learning Resources and Students' Psychological State

Digital learning resources allow for online learning when they contain accessible, relevant, and structured information that helps students understand the concepts, prepare for practical tasks, and review the instructional material. According to the cognitive theory of multimedia learning, carefully crafted learning resources help in promoting cognitive processing through the reduction of extraneous cognitive load (Mayer, 2020). However, in the case of technical education, the importance of digital resources lies in their incorporation in relevant pedagogical processes rather than just their presence. Well-organized and task-related resources can contribute positively to confidence, motivation, and preparedness for learning (Bond et al., 2020).

H₂: Digital learning resources have a positive effect on students' psychological state in online learning within practice-oriented technical education.

3.3. Interaction Environment and Students' Psychological State

The importance of academic interaction for distance learning lies in feedback, explanation, and social presence required to motivate learners and make them actively participate in the distance learning process. Within practice-oriented technical education, such interaction fulfills another task; it helps students comprehend practical requirements and connect theoretical explanations with practical actions, and thus minimizes the lack of immediacy of face-to-face supervision. Hence, social and instructional presence facilitate participation as well as psychological preparation of learners in an online setting (Borup et al., 2020; Garrison et al., 1999; Martin et al., 2018).

H₅: The academic interaction environment has a positive effect on students' psychological state in online learning within practice-oriented technical education.

3.4. Psychological State of Learners and Online Learning Effectiveness

Students' psychological state impacts their ability to persist in efforts, control the process of learning, and stay motivated during online learning processes. According to self-efficacy theory, belief in one's capability to perform results in greater motivation, persistence, and success (Bandura, 1997). Within practice-oriented online learning, this dimension acquires importance due to the uncertainty of practical assignments, limited possibilities to use laboratory equipment, and a lack of direct supervision. Psychologically prepared learners appear to be more motivated and engaged in the distance learning process (Bond et al., 2020; Gamage, Perera, & Fernando, 2020).

H₆: Students' psychological state positively impacts online learning effectiveness.

3.5. The Role of Students' Psychological State as a Mediator

Students' psychological state is considered the mediating factor between the conditions of online learning and the perception of its effectiveness. In the context of online and blended applied education, the use of educational strategies, information resources, and interaction opportunities might impact the effectiveness of studying by increasing motivation, involvement, confidence, and willingness to study.

Prior SEM studies have suggested that learner factors might mediate the association between features of the learning environment and the outcomes of education (Ifenthaler & Yau, 2020; Kuo et al., 2014). As the use of psychological readiness becomes critical for learners in technical education due to less supervision and limited access to laboratories, the following mediating hypotheses are presented:

H₇: Students' psychological state is the mediator between pedagogical methods and the perception of online learning effectiveness.

H₈: Students' psychological state is the mediator between digital learning resources and the perception of online learning effectiveness.

H₉: Students' psychological state is the mediator between the academic interaction environment and the perception of online learning effectiveness.

4. THE METHODOLOGY

4.1. Empirical Design and PLS-SEM Approach

A quantitative research design was used to test the relationships among the five latent constructs of the proposed model in regulated-access technical education. Since the theoretical model is predictive and consists of several latent constructs, Partial Least Squares Structural Equation Modeling (PLS-SEM) was preferred as the main method of analysis. PLS-SEM is an appropriate technique when dealing with variance-oriented education-related models (Hair, Hult, Ringle, & Sarstedt, 2021).

4.2. Research Context and Participants

Empirical data were gathered from students registered in regulated-access engineering courses within Morocco. In particular, the dataset consisted of engineering students attending engineering courses at the Higher School of Technology of Casablanca, Hassan II University, and other similar public universities. Overall, 401 surveys were completed. As for the field of specialization, respondents specialized in various practice-oriented engineering fields: mechanical engineering (46.6%), computer engineering (28.2%), and electrical engineering (25.2%). In terms of academic performance, 55.6% of students were studying in the second year, whereas 44.4% were first-year students.

4.3. Procedure of Data Collection

The data were gathered through a survey that was administered among students studying in regulated-access education programs. The questionnaire was administered electronically during the academic year. Participation was voluntary; all data were anonymous to ensure participants' confidentiality. Respondents gave information about their demographics, including age, gender, level of study, and academic major.

4.4. Measurement of Constructs

Measures for constructs were based on items previously used in other studies and modified to the context of regulated-access technical education. The proposed model included five latent constructs.

- Pedagogical Methods (PM): Clarity, quality, and effectiveness of instructional practices used in online and hybrid learning contexts.
- Digital Learning Resources (DLR): Accessibility, relevance, and quality of digital materials supporting theoretical understanding, preparation for practical tasks, and continuity between online learning and laboratory-based activities.
- Academic Interaction Environment (AIE): Communication, feedback, and interaction between students and instructors.
- Students' Psychological State (SPS): Motivation, emotional engagement, confidence, and readiness to learn;
- Perceived Effectiveness of Online Learning (PEOL): students' perception of learning quality and effectiveness in digital learning environments.

All the mentioned constructs were measured using a five-point Likert scale (1 – *strongly disagree*; 5 – *strongly agree*) (Likert, 1932). All latent constructs were reflective since the corresponding manifest items represent these latent constructs.

4.5. Data Preparation and Statistical Analysis

Data preparation was done initially using SPSS, which enabled the coding, screening, and cleaning processes before statistical analysis. This step involved checking for consistency in the responses provided, preparing the variables for analysis, and ensuring the suitability of the dataset for modeling. XLSTAT was then used to conduct descriptive analysis, assess measurement-model quality, and estimate the PLS-SEM model.

The statistical analysis was done in such a way that an interpretation of the postulated model would be possible only after validating the model's measurement quality. At the first stage, the reflective measurement model was analyzed for its consistency and validity for the five hypothetical constructs. Internal reliability was assessed using Cronbach's alpha and composite reliability, while convergent validity was examined using average variance extracted. Discriminant validity was established with the help of the Fornell-Larcker criterion and the heterotrait-monotrait (HTMT) ratio. These tests were used to verify whether the five constructs of the model represented distinct empirical dimensions (Fornell & Larcker, 1981; Hair et al., 2021).

Once the measurement properties of the constructs had been verified, the structural relationships proposed in the conceptual model were examined. Standardized coefficients were estimated for the paths linking pedagogical methods, digital learning resources, the academic interaction environment, students' psychological state, and perceived effectiveness of online learning. Statistical significance was assessed through a 5,000-resample bootstrapping procedure, including both direct and mediated paths. Model performance was then evaluated using R^2 for explained variance, f^2 for the relative contribution of each predictor, and Stone-Geisser's Q^2 for predictive relevance. This sequence ensured that the interpretation of the structural paths followed the validation of the measurement model.

4.6. Mediation Analysis

The mediating role of students' psychological state was examined through bootstrapped indirect effects. This procedure made it possible to determine whether pedagogical methods, digital learning resources, and academic interaction environment influenced the perceived effectiveness of online learning indirectly through students' psychological state.

5. RESULTS

5.1. Measurement Model Assessment

Before testing the structural relationships, the fitness of the measurement model was checked first. This analysis considered the internal consistency of the items with respect to their corresponding constructs and determined if the variance of each construct could be explained by the indicators. For internal consistency, Cronbach's alpha and composite reliability were applied. In addition to this, AVE was utilized for convergent validity. As shown in Table 1, Cronbach's alpha scores were all above 0.872 and below 0.914, exceeding the suggested cut-off score of 0.70. On the other hand, the composite reliability scores ranged between 0.903 and 0.931, while AVE scores were all above 0.602 and below 0.694.

Table 1. Measurement Model Quality Assessment.

Construct	Number of Items	Cronbach's Alpha	Composite Reliability	AVE	Interpretation
PM	5	0.901	0.923	0.668	Excellent
DLR	6	0.887	0.912	0.635	Very good
AIE	6	0.914	0.931	0.694	Excellent
SPS	6	0.872	0.903	0.608	Very good
PEOL	7	0.884	0.911	0.602	Very good

5.2. Discriminant Validity Assessment

The distinctiveness of the constructs was examined using the Fornell–Larcker criterion (Fornell & Larcker, 1981) and the HTMT ratio (Hair et al., 2021). The resulting correlations between constructs were lower than the square roots of AVE, which ranged from 0.776 to 0.833. These findings indicate that the constructs capture related but empirically distinct dimensions of the online learning process.

5.3. Analysis of the Structural Model

The structural model was analyzed through bootstrapped path estimation, standard error analysis, t-value evaluation, and p-value assessment. According to Table 2, all of the predicted direct paths proved statistically significant, with t-values greater than the critical value of 1.96 at the 5% level of significance.

The direct effects reported in Table 2 confirm the statistical significance of all hypothesized relationships. In the order β , t-value, and p-value, the estimated values are: PM $\rightarrow$ SPS (0.214, 3.10, 0.002), DLR $\rightarrow$ SPS (0.168, 2.55, 0.011), AIE $\rightarrow$ SPS (0.381, 5.86, < 0.001), and SPS $\rightarrow$ PEOL (0.463, 7.23, < 0.001). These results support H1, H2, H3, and H4, with the academic interaction environment showing the strongest direct effect on students' psychological state.

Table 2. Structural Model Path Coefficients and Hypothesis Testing Results.

Hypothesis	Relationship	Path Coefficient (β)	Standard Error	t-value	p-value	Decision
H1	PM $\rightarrow$ SPS	0.214	0.069	3.10	0.002	Supported
H2	DLR $\rightarrow$ SPS	0.168	0.066	2.55	0.011	Supported
H3	AIE $\rightarrow$ SPS	0.381	0.065	5.86	< 0.001	Supported
H4	SPS $\rightarrow$ PEOL	0.463	0.064	7.23	< 0.001	Supported

5.4. Coefficient of Determination and Effect Size

The explanatory capacity of the model was assessed using R^2 and adjusted R^2 . According to Chin (1998), as presented in Table 3, pedagogical methods, digital learning resources, and academic interaction environment predict 42.3% of the variation in students' psychological state ($R^2=0.423$, adjusted $R^2=0.418$). On the other hand, students' psychological state predicts 37.1% of the variation in the perceived effectiveness of online learning ($R^2=0.371$, adjusted $R^2=0.369$).

Table 3. Coefficients of Determination.

Endogenous Construct	Predictor Variables	R^2	Adjusted R^2	Interpretation
SPS	PM, DLR, AIE	0.423	0.418	Moderate explanatory power
PEOL	SPS	0.371	0.369	Moderate explanatory power

To determine how much each predictor contributes to the prediction of students' psychological state and perceived effectiveness of online learning, the effect size f^2 was calculated. In line with the recommendations of Cohen (1988), effect sizes of 0.02, 0.15, and 0.35 can be considered small, medium, and large, respectively.

Table 4. Effect Size of Structural Relationships.

Relationship	f^2	Effect Size Interpretation
PM $\rightarrow$ SPS	0.071	Small to medium
DLR $\rightarrow$ SPS	0.048	Small
AIE $\rightarrow$ SPS	0.186	Medium
SPS $\rightarrow$ PEOL	0.298	Medium to large

Table 4 indicates that the academic interaction environment has the greatest effect on students' psychological state ($f^2=0.186$), thus indicating a medium effect. Pedagogical methods exhibit a small effect ($f^2=0.071$), as well as digital learning resources ($f^2=0.048$). Moreover, students' psychological state exerts a medium-to-large effect ($f^2=0.298$) on the perceived effectiveness of online learning.

5.5. Model Fit and Predictive Relevance

The Goodness-of-Fit index, which combines the average communality of the measurement model with the explanatory power of the structural model, was used to assess overall model adequacy (Tenenhaus, Vinzi, Chatelin, & Lauro, 2005; Wetzels, Odekerken-Schröder, & Van Oppen, 2009). The computed GoF value was 0.493, demonstrating the suggested model's good overall adequacy.

Table 5. Goodness-of-Fit Index of the Structural Model.

Construct	AVE	R^2
Pedagogical Methods (PM)	0.61	-
Digital Learning Resources (DLR)	0.58	-
Academic Interaction Environment (AIE)	0.63	-
Students' Psychological State (SPS)	0.59	0.423
Perceived Effectiveness of Online Learning (PEOL)	0.65	0.371

Mathematically, the GoF index is defined as:

$$\text{GoF} = \sqrt{\text{Average AVE} \times \text{Average } R^2} \quad (1)$$

Where Average AVE represents the average AVE value across all constructs, and Average R^2 represents the average R^2 value across endogenous constructs.

Based on the information in Table 5, the value of GoF is calculated as:

$$\text{Goodness - of - Fit (GoF)} = 0.493 \quad (2)$$

Using Stone-Geisser's Q^2 , predictive relevance was investigated. Both endogenous dimensions, Students' Psychological State (0.286) and perceived effectiveness of online learning (0.241), had positive Q^2 values, as Table 6 illustrates. These findings suggest that both endogenous variables can be predicted by the model (Hair et al., 2021).

Table 6. Predictive Relevance (Q^2).

Endogenous Construct	Q^2	Predictive Relevance
Students' Psychological State (SPS)	0.286	Adequate
Perceived Effectiveness of Online Learning (PEOL)	0.241	Adequate

These positive Q^2 values indicate satisfactory predictive relevance for both endogenous constructs.

5.6. Structural Equations

Based on the estimated structural model, there are two endogenous constructs: Students' Psychological State (SPS) and Perceived Effectiveness of Online Learning (PEOL). SPS depends on pedagogical methods (PM), digital learning resources (DLR), and academic interaction environment (AIE), while PEOL depends on SPS.

The first equation describes how instruction-related factors impact students' psychological state.

$$SPS = \beta_1 PM + \beta_2 DLR + \beta_3 AIE + \varepsilon_1 \quad (3)$$

Where ε_1 denotes the residual error term.

By incorporating the estimated path coefficients from Table 2, Equation 3 becomes:

$$SPS = 0.214 PM + 0.168 DLR + 0.381 AIE + \varepsilon_1 \quad (4)$$

The second equation expresses the relation of students' psychological state to their perception of online learning effectiveness.

$$PEOL = \beta_4 SPS + \varepsilon_2 \quad (5)$$

Where ε_2 is the residual error term.

Incorporating Equation 5 with the corresponding path coefficient, one gets the following.

$$PEOL = 0.463 SPS + \varepsilon_2 \quad (6)$$

Thus, the above equations demonstrate the estimated model's causal structure and are consistent with the path coefficients provided in Table 2.

5.7. Mediation and Total Effects

Mediation for the effects of pedagogical methods, digital learning resources, and academic interaction environment on the perceived effectiveness of online learning has been investigated via bootstrapping. As follows from Table 7, indirect effects are statistically significant concerning H5, H6, and H7.

The mediation effects presented in Table 7 confirm the significance of three indirect effects. By using the order β , t-value, and p-value, we get $PM \rightarrow SPS \rightarrow PEOL$ (0.099, 2.36, 0.018), $DLR \rightarrow SPS \rightarrow PEOL$ (0.078, 2.11, 0.035), and $AIE \rightarrow SPS \rightarrow PEOL$ (0.176, 4.56, < 0.001). Thus, the results support H5, H6, and H7, indicating students' psychological state as a mediator variable.

Table 7. Mediation Effects Based on Bootstrapping Results.

Hypothesis	Indirect Relationship	Indirect Effect (β)	t-value	p-value	Result
H5	$PM \rightarrow SPS \rightarrow PEOL$	0.099	2.36	0.018	Supported
H6	$DLR \rightarrow SPS \rightarrow PEOL$	0.078	2.11	0.035	Supported
H7	$AIE \rightarrow SPS \rightarrow PEOL$	0.176	4.56	<0.001	Supported

Table 8 indicates that students' psychological state has the strongest direct effect on the perceived effectiveness of online learning ($\beta = 0.463$). Among the indirect effects, the academic interaction environment shows the strongest contribution ($\beta = 0.176$), followed by pedagogical methods ($\beta = 0.099$) and digital learning resources ($\beta = 0.078$).

Table 8. Total Effects in the Proposed Structural Model.

Relationship	Direct Effect	Indirect Effect	Total Effect
PM $\rightarrow$ PEOL	—	0.099	0.099
DLR $\rightarrow$ PEOL	—	0.078	0.078
AIE $\rightarrow$ PEOL	—	0.176	0.176
SPS $\rightarrow$ PEOL	0.463	—	0.463

6. DISCUSSION

6.1. Interpretation of the Main Findings

The results highlight the need for a multifaceted interpretation of online learning effectiveness in regulated-access technical education. Rather than reducing online learning effectiveness solely to factors like technology acceptance, satisfaction, and engagement, the findings reveal that students' perception is influenced by the combined effects of pedagogical methods, digital learning resources, academic interaction, and students' psychological state. This notion resonates with other studies suggesting that online learning effectiveness depends on instructional design, system quality, academic interaction, engagement, and perceived usefulness (Al-Fraihat et al., 2020; Alqahtani et al., 2022; Garrison et al., 1999; Li & Zhu, 2022; Martin & Bolliger, 2018).

The model demonstrates moderate explanatory ability. The combination of pedagogical methods, digital learning resources, and academic interaction environment explains 42.3% of the variance in students' psychological state. Further, students' psychological state accounts for 37.1% of the variance in perceived effectiveness of online learning. Thus, it can be argued that online learning in technical courses is meaningful and effective when learning conditions allow students to develop the psychological readiness, motivation, and confidence necessary for participation in online learning activities. The results are in line with numerous studies that demonstrate the relationship between psychological dimensions such as engagement, self-regulation, psychological readiness, and motivation and students' learning behavior (Bandura, 1997; Bond et al., 2020; Kahu & Nelson, 2018; Ryan & Deci, 2020; Schunk & DiBenedetto, 2020).

Out of three variables under consideration, the academic interaction environment has the highest impact on students' psychological state ($\beta = 0.381$, $p < 0.001$). This observation corresponds with previous studies highlighting interaction as a multi-dimensional concept encompassing both communication and feedback, as well as social and teaching presence in the context of online learning (Borup et al., 2020; Garrison et al., 1999; Kuo et al., 2014; Martin & Bolliger, 2018; Martin et al., 2018). In terms of regulated-access technical education, this finding has particular importance since interaction helps students make connections between theoretical explanations and laboratory-based requirements, including applied procedures and tasks.

Another variable that shows considerable impact on students' psychological state is pedagogical methods ($\beta = 0.214$, $p = 0.002$). This suggests that students feel more confident and motivated to participate in learning activities when pedagogical methods and activities are organized properly. The result is consistent with other studies that link instructional design, teacher presence, facilitative strategies, and sequencing of learning activities with motivation, engagement, and conceptual understanding (Escueta et al., 2020; Garrison et al., 1999; Martin et al., 2018; Mayer, 2020). As far as regulated-access technical education is concerned, pedagogical methods have added value as they help students understand what they are expected to learn during online activities.

Finally, the last predictor that has a significant but lower impact on students' psychological state is digital learning resources ($\beta = 0.168$, $p = 0.011$). At first glance, this might seem contradictory, although it reflects the true role of digital resources in technical education. Learning platforms, multimedia materials, simulations, online

exercises, laboratory videos, and other resources are valuable for students if they are used in combination with pedagogical guidance and learning interactions. This interpretation resonates with studies focusing on e-learning system quality, accessibility of digital learning resources, learning analytics, and virtual laboratory applications (Al-Fraihat et al., 2020; Almaiah et al., 2020; Elmoazen et al., 2023; Ifenthaler & Yau, 2020; Li & Zhu, 2022).

Lastly, it should be highlighted that students' psychological state has strong positive effects on perceived effectiveness of online learning ($\beta = 0.463$, $p < 0.001$). The finding is in line with other studies showing that psychological dimensions are critical for determining students' experience of online learning conditions, which, in turn, can explain their willingness to continue learning. Indeed, psychological aspects of learning are strongly correlated with learners' self-efficacy, motivation, psychological needs, and engagement, and affect their learning experience significantly (Bandura, 1997; Bond et al., 2020; Kahu & Nelson, 2018; Ramis & Cheong, 2024; Ryan & Deci, 2020; Schunk & DiBenedetto, 2020). In regulated-access technical education, psychological state plays a particularly important role since students are required to stay involved in learning activities despite limitations of some learning components.

Overall, it can be concluded that regulated-access online learning effectiveness in technical education cannot be achieved using digital resources alone. Although laboratory videos, simulations, remote laboratory practices, and other digital learning materials might help students prepare and better understand concepts, their value depends on the way they are organized pedagogically and academically. This conclusion is supported by numerous studies indicating that virtual and online laboratories are helpful in technical education when used as additions to supervised laboratory practices (Charitopoulos et al., 2022; Chowdhury et al., 2019; Faulconer & Gruss, 2018; García-Ros & Alhama, 2023; Kapilan et al., 2021; Kiravu et al., 2016; May et al., 2023; Wörner et al., 2022).

6.2. Mediation Effect of Students' Psychological State

The current study shows clearly that students' psychological state plays a key role in the process of regulated-access online learning. According to the mediation analysis, the impact of pedagogical methods, digital learning resources, and academic interaction on online learning effectiveness takes place indirectly through students' psychological state. All three indirect effects are statistically significant: pedagogical methods $\rightarrow$ students' psychological state $\rightarrow$ perceived effectiveness of online learning ($\beta = 0.099$, $p = 0.018$), digital learning resources $\rightarrow$ students' psychological state $\rightarrow$ perceived effectiveness of online learning ($\beta = 0.078$, $p = 0.035$), and academic interaction environment $\rightarrow$ students' psychological state $\rightarrow$ perceived effectiveness of online learning ($\beta = 0.176$, $p < 0.001$).

In other words, online learning conditions become effective through the mediation of the psychological dimensions of students. Organized teaching, accessible learning resources, and academic interaction have higher chances of contributing positively to students' experience of online learning when they motivate students, make them feel ready, interested, and confident in their ability to perform various learning activities. The interpretation is consistent with self-determination theory, suggesting that the development of students' autonomy, competence, and relatedness fosters motivation and learning behavior (Ryan & Deci, 2020). It is also in line with studies linking engagement, self-regulation, and psychological factors with students' learning behavior and academic progress (Bond et al., 2020; Kahu & Nelson, 2018; Schunk & DiBenedetto, 2020).

Out of all indirect effects, the strongest one refers to the academic interaction environment. The fact that the impact of academic interaction environment on online learning effectiveness is realized through students' psychological state is crucial for regulated-access technical education, as students require ongoing interaction and feedback to make theoretical explanations compatible with laboratory expectations and applied procedures. Such interpretation is consistent with the notion of the Community of Inquiry as developed by Garrison et al. (1999). The result is also corroborated by studies confirming the importance of interaction for online engagement and academic motivation (Borup et al., 2020; Kuo et al., 2014; Martin & Bolliger, 2018; Martin et al., 2018).

It is particularly noteworthy that the role of psychological state is prominent in the context of technical education due to its emphasis on practice and hands-on experience. With access to laboratories and equipment being limited, students might have doubts regarding the utility of online learning resources, such as laboratory videos and simulations, for practical application.

Thus, students' psychological state becomes a factor through which learning conditions acquire educational value. While online resources and virtual simulations could contribute to preparation for practical learning, their impact would be weak if students felt unmotivated and unsupported. This idea finds support in studies confirming the efficacy of online resources as complements to supervised experiments (Faulconer & Gruss, 2018; García-Ros & Alhama, 2023; Kapilan et al., 2021; Kiravu et al., 2016; May et al., 2023; Wörner et al., 2022).

6.3. Relevance and Implications for Regulated-Access Technical Education

As discussed above, regulated-access technical education requires a strong connection between theoretical instruction, practice, and laboratory-based competence development. Online and hybrid learning face difficulties in that regard, since they can support students' preparation for practical learning activities, their conceptual understanding, and practice repetition, but fail to provide manipulation, direct supervision, and immediate feedback available in laboratory learning. The idea is corroborated by other studies discussing the benefits of laboratory videos, virtual laboratories, simulations, and online practical tasks when used as additional learning resources (Faulconer & Gruss, 2018; García-Ros & Alhama, 2023; Kapilan et al., 2021; Kiravu et al., 2016; May et al., 2023; Wörner et al., 2022).

In theory, the results of the study make a new contribution by offering a model in which regulated access to online education in technical programs is not explained through technology, satisfaction, or motivation. Regulated access to online education can only be explained by the combined influence of teaching methodology, digital learning resources, academic interaction, and the psychological state of students. In practice, the results of the research suggest that, when designing online or hybrid technical education courses, digital resources should be used as an auxiliary means of organizing the educational process.

7. CONCLUSION

The analysis focused on a specific issue in regulated-access technical education: how online learning remains meaningful when practical training and laboratory supervision are central to the curriculum. The results show that digital provision alone is not enough to explain students' perceptions of learning effectiveness. Instructional organization, digital support, academic interaction, and psychological readiness work together in shaping how students evaluate online learning.

The structural results give particular weight to academic interaction, which was the strongest predictor of students' psychological state ($\beta = 0.381$). Pedagogical methods and digital learning resources also contributed significantly to this psychological dimension ($\beta = 0.214$; $\beta = 0.168$). Students' psychological state then predicted perceived effectiveness of online learning ($\beta = 0.463$). These findings underline the importance of communication, feedback, guidance, and student readiness when online learning is expected to remain connected to practical and laboratory-based training.

The model gives a central place to students' psychological state, not as an isolated outcome, but as the link through which learning conditions become meaningful for students. For institutions, the implication is direct: online and hybrid environments in technical education should preserve the logic of supervision through structured feedback, guided activities, and explicit connections with practical requirements.

Several limitations should be acknowledged. First, the cross-sectional design does not allow changes over time to be examined. Second, learners' perceptions rather than performance measures were used as dependent variables.

Finally, although several specializations were considered, greater institutional diversity could support more generalizable results.

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Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.

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