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Unveiling key e-learning ingredients for enhancing higher-order thinking skills

Chua Yan Piaw[1,2] · **Loo Fung Ying**[3] · **Loo Fung Chiat**[4]

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Abstract
The existing e-learning models for higher-order thinking skills (HOTS) enhancement focus more on technology and e-learning methods, ignoring the important roles of human factors such as e-leadership, collaboration, and readiness. This exploratory sequential mixed-methods design study aimed to identify significant factors for e-learning practices that enhance HOTS. Semi-structured interviews were conducted with school administrators, teachers, students, parents, and school software experts, and the transcripts were analyzed using ATLAS.ti. Seven core factors emerged from the study: collaboration, readiness, e-leadership, personal factors, strategies, practices, and organizational factors. Their associations were verified through a quantitative survey involving 430 secondary school teachers. The quantitative data was analyzed using PLS-SEM and cIPMA in SMARTPLS 4, resulting in five sub-models defining a HOTS enhancement framework for schools e-learning. E-learning practices, strategies, collaboration, organizational factors, readiness, and e-leadership are six significant necessities for enhancing higher-order thinking skills (HOTS). Besides that, 41.302% of school leaders and teachers did not meet the minimum required level of e-leadership needed to achieve at least 80% HOTS enhancement in e-learning. This highlights the critical role of school leaders and teachers in leveraging e-leadership within e-learning platforms. This research provides a new model that educational leaders, policymakers, and educators can adopt to enhance HOTS in e-learning.

Keywords E-learning · Higher order thinking skills · E-learning practices · Secondary school · Quality education

1 Introduction

E-learning refers to the use of digital technologies and internet resources to deliver educational content and support learning processes [2, 34]. It has advantages over conventional classroom learning such as access to a wide range of interactive multimedia resources, self-paced instruction and personalized learning. Previous studies have shown that interactive e-learning can boost learning engagement and motivation [20, 38] and enhance higher-order thinking skills (HOTS) in students [27, 45]. HOTS involves the ability to think critically and creatively, solve non-routine and complex problems, and make right decisions through advanced cognitive processes such as assessing, synthesizing, evaluating, analyzing and reflecting information, and creating new, original and useful ideas. Developing HOTS is

✉ Chua Yan Piaw, chuayp@ucsiuniversity.edu.my; chuayp@um.edu.my; Loo Fung Ying, loofy@um.edu.my; Loo Fung Chiat, lfc@upm.edu.my | [1]Faculty of Social Sciences and Liberal Arts, UCSI University, Kuala Lumpur, Malaysia. [2]Faculty of Education, Universiti Malaya, Kuala Lumpur, Malaysia. [3]Faculty of Creative Arts, Universiti Malaya, Kuala Lumpur, Malaysia. [4]Faculty of Human Ecology, Universiti Putra Malaysia, Kuala Lumpur, Malaysia.

essential for students to solve daily problems, improve academic performance, and foster career advancement and lifelong learning [5].

The increasing usage of e-learning platforms in schools provides opportunities for students to improve their higher-order thinking skills (HOTS) [4]. Although e-learning in schools can improve students' content knowledge [39], its effectiveness in fostering HOTS remains limited and unclear [25], as the existing e-learning models focus more on technological tools and teaching methods, which often ignore the important roles related to human factors such as e-leadership, collaboration, and readiness [23]. This situation has resulted in the inconsistent effectiveness of e-learning in fostering HOTS, where e-leadership, collaboration, and readiness factors of administrators, teachers, students, and parents are less emphasized, leading to the practice of e-learning not being maximized [35].

Although the cultivation of students' HOTS has been the focus in schools, the limited understanding of school practitioners, administrators, teachers, parents, and students about the factors that drive HOTS in e-learning platforms is insufficient due to the lack of a framework that links all factors that can foster students' higher-order thinking skills [18]. Without comprehensive knowledge, educators and policymakers have difficulty designing e-learning strategies that can effectively maximize HOTS among students.

Therefore, this study aims to address the above knowledge gap by investigating the key factors that can foster HOTS in e-learning from the perspective of various parties who are directly and indirectly involved with e-learning platforms in schools. The results of this study would suggest actions for educational policymakers, school leaders, and e-learning platform developers to provide a more conducive e-learning environment for fostering HOTS among students. Additionally, it contributes to the body of knowledge by developing a new e-learning model for enhancing HOTS, which serves as a valuable guide for improving HOTS in schools through e-learning platforms.

2 Literature review

Several e-learning models have been used to guide e-learning processes. These models integrate teaching with technology to enhance e-learning. For instance, the SAMR model, the TPACK model, the PTEACES model and the TAM model. The models focus more on integrating teaching methods and the use of technology [33], and less emphasis on the dynamics between schools, leaders, teachers and students, which is highly important for the development of students' high order thinking [6]. For example, the SAMR model [37] emphasizes linking technology to pedagogy but does not address how technology can be utilized to enhance higher-order thinking skills [7]. The TPACK model [32] focuses on the intersection of technological knowledge, pedagogical knowledge and content knowledge but overlooks human factors, such as students' motivation, attitude, engagement and commitment which influence cognitive and mental development in e-learning [44]. Similarly, the PTEACES model [28] focuses on e-learning environment itself. Although this model integrates technology with teaching methods and is student-centered, the model neglects the role of e-leaders and organizational readiness in developing higher-order thinking skills among students. The Technology Acceptance Model (TAM) [13], focuses primarily on two key factors that influence technology adoption: perceived usefulness and perceived ease of use, is widely used to understand how users accept and use technology. It has a limitation in that it does not specifically emphasize the enhancement of HOTS in learners.

Meanwhile, the focuses of most recent studies are mainly on the impacts of individual e-learning methods and platforms on critical thinking and creative thinking (see Table 1). For examples, the impact of discussion forum in e-learning [16], the integration of gamification in e-learning project [20], the effect of peer online teaching tools [36], the role of multimedia tools [29, 46], the impacts of project-based learning [10, 45], the uses of collaborative tools [1] and the effectiveness of interactive platforms [27]. Besides the limitations of small sample sizes, demography constraints and subjective data collection methods, the previous studies fail to address the knowledge gaps, to provide a larger picture for our understanding on how HOTS be cultivated through e-learning.

Based on the existing literature and the fact that enhancing HOTS in students is one of e-learning objectives, there is an urgent need to conduct a study to develop a model that can serve as a guide for fostering HOTS through e-learning.

In developing the model, Creswell's paradigm model [8, 11, 12, 21, 43] will be used to guide the information-gathering process in the study. The framework of the paradigm model includes six core themes: phenomenon (enhancing HOTS through e-learning), causal conditions, context, intervening conditions, strategies, and consequences.

Table 1 Recent research on enhancing higher order thinking skills through e-learning

Authors (year)	Research method and sampling	Findings
Firdaus et al. (2024) [16]	Quasi-experimental design; third-year university students; cluster random sampling	Discussion forums in e-learning improved critical thinking. Engagement and collaboration are significant factors for e-learning
Gejandran and Abdullah (2024) [20]	Reviewed 37 studies published in the past decade, between 2014 and 2023	Gamification in e-learning improved student motivation and engagement levels. Game elements enhance HOTS
Zunaidah and Asih (2024) [46]	Design and development research; 52 English learners (N = 52); convenience sampling	E-learning with multimedia tools improved student engagement and critical thinking in an online English language course
Yu (2024) [45]	An extensive literature review on Project-based learning, including e-learning	Project-based e-learning modules significantly enhanced both creative and critical thinking
Ekayana et al. (2024) [15]	Quasi-experimental pretest-post-test non-equivalent control group design; 150 university engineering students; purposive sampling	High academic self-efficacy in e-learning have higher learning achievement and creative thinking skills than students with low academic self-efficacy
Irwan (2024) [27]	Experimental study; vocational high school students; convenience sampling	Interactive video-based e-learning improved critical thinking skills
Alharbi et al. (2022) [1]	Experimental study; 200 female students of kindergarten department in a university; random assigned into experimental and control groups	E-collaborative learning environment had significant and positive effect on development of critical thinking
Page (2022) [36]	Survey; participants were pre-service teacher education students enrolled in an online university course (N = 625); purposive sampling	Peer online teaching tool enhanced HOTS in students
Cortazar et al. (2021) [10]	Experimental study; 834 students at an engineering school	Online project-based learning fostered the development of critical thinking
Lee & Choi (2017) [31]	Survey study, 487 undergraduates; random sampling	Readiness in terms of epistemological beliefs, approach to learning, and attitudes toward technology use affected higher-order thinking in technology-enhanced learning environments
Kassim (2013) [29]	Quasi-experimental study with one group pre-test post-test design; Mechanical engineering undergraduates (N = 32; 97% male)	Multimedia learning tool enhanced creative thinking of active, reflective, intuitive and high visual students

3 The study

The aim of this study was to develop an e-learning HOTS enhancement model among secondary school students. This *exploratory sequential mixed methods* design study was first carried out with a qualitative study. Semi-structured interviews were conducted on school administrators, teachers, students, parents, and software experts to gather information about the implementation and practices of e-learning in schools. The qualitative transcripts were then analyzed using the *ATLAS.TI* software to identify significant indicators and themes, and their associations for HOTS enhancement in e-learning.

The study was then followed by a quantitative survey on 430 school teachers to validate the model emerged from the qualitative study. The model was analyzed to examine the importance and performances of the variables in the model, as well as the levels of each variable necessary for achieving quality outcome for HOTS enhancement. The quantitative data was analyzed with *PLS-SEM (Partial Least Squares Structural Equation Modeling)* and *cIPMA* (*Combined Importance Performance Map Analysis*) using SMARTPLS 4 software.

3.1 The qualitative study

3.1.1 Participants

The study used theoretical sampling to select key participants with direct and indirect experience in a school e-learning platform. The sample included five school administrators, five teachers, five students, five parents, and five software experts. These diverse groups were chosen to provide rich insights into the e-learning practices in secondary schools in enhancing HOTS.

3.1.2 Research instruments

Three inventories were created for data collection: The *School Administrators Inventory* which focused on e-leadership and management roles, the *Teacher, Student, and Parent Inventory*, focused on personal and organizational factors, and the *Software Expert Inventory*, focused on technical aspects of the e-learning platforms. They covered planning, implementation, support, challenges, collaboration and recommendations for improving e-learning practices in schools through the e-learning platforms to enhance higher order thinking skills in students.

3.1.3 Qualitative data analysis

The transcripts of the interview data were first coded by *open coding* using the ATLAS.ti software and break down into manageable indicators. *Axial coding* was then used to identify similarities and differences between the indicators to investigate how the data are gathered in categories of data and associated into themes, to explain the data in a meaningful way. Through the axial coding process, eight key themes emerged from thirty-eight indicators in the qualitative transcripts: collaboration, e-learning readiness, e-leadership, personal factors, e-learning strategies, e-learning practices, organizational factors and quality outcomes (see Table 2).

Selective coding was then used to identify the associations between the eight themes. By referring to Spradley's *semantic relations* criteria [42], i.e., strict inclusion (A is a property of B), spatial (A is part of B), cause-effect (A is a cause of B), and rationale (A is an outcome of B), the associations between the themes were identified (see Fig. 1).

3.2 The quantitative study

3.2.1 Participants

The population of the study consists of secondary schools in a district in the state of Selangor, Malaysia. There are 39 secondary schools in the district, with approximately 5,600 secondary school teachers. Selecting approximately 10% of the population is considered acceptable for small populations in educational research [17]. Accordingly, four schools

Table 2 Domain analysis outputs—the eight themes that emerged from the interview transcripts

Indicators	Code	Themes (number of indicators)
1. Design collaborative e-learning curriculum-related activities for fostering HOTS	CO1	Collaboration (4)
2. Establish e-learning's working committees which focus on HOTS	CO2	
3. Design group problem-based e-learning projects that enhance HOTS	CO3	
4. Maximize feedback loops to promote HOTS in students	CO4	
5. Enhance students' knowledge of HOTS in e-learning	RE1	Readiness (6)
6. Regularly evaluate school technology infrastructures for HOTS enhancement	RE2	
7. Create school policies that promote HOTS through e-learning	RE3	
8. Implement training courses that focus on fostering HOTS	RE4	
9. Encourage mindset change among students, teachers and school administrators	RE5	
10. Cultivate positive attitude of students, teachers and school administrators towards e-learning	RE6	
11. Develop a mission and vision for integrating HOTS into e-learning	LE1	e-leadership (4)
12. Provide e-leadership training for administrators and teachers to improve knowledge of enhancing HOTS through e-learning	LE2 LE3	
13. Promote leadership initiatives that promote HOTS	LE4	
14. Encourage innovative practices to foster HOTS		
15. Consider students' needs related to HOTS development	PE1	Personal factors (5)
16. Promote positive attitude through interactive HOTS activities	PE2	
17. Encourage students' involvement in HOTS participation	PE3	
18. Create teachers' commitment in e-learning platforms that foster a culture of HOTS	PE4	
19. Encourage HOTS through self-directed e-learning among students	PE5	
20. Use inquiry-based approaches in e-learning to foster HOTS	ST1	e-learning strategies (4)
21. Accept different views in e-learning to enhance HOTS	ST2	
22. Integrate creative multimedia resources in e-learning to enhance HOTS	ST3	
23. Develop interdisciplinary e-learning projects focusing on HOTS	ST4	
24. Maximize the use of discussion and forums to enhance HOTS	PR1	e-learning practices (5)
25. Incorporate multiple simulations in e-learning platforms to develop HOTS	PR2	
26. Use varied assessment methods that focus on HOTS	PR3	
27. Apply continuous assessment on e-learning practices for HOTS enhancement	PR4	
28. Share best e-learning practices for developing HOTS among teachers	PR5	
29. Provide sufficient technical support for improving HOTS in e-learning	SU1	Organizational factors (6)
30. Provide sufficient institutional backing for professional development focused on HOTS	SU2	
31. Provide HOTS online resources for teachers	SU3	
32. Cultivate community engagement to support HOTS initiatives	SU4	
33. Implement supportive policies from educational authorities to promote HOTS among students	SU5	
34. Develop partnerships with external organizations that facilitate students' HOTS development	SU6	
35. Positive feedback from stakeholders on HOTS quality in e-learning	QU1	Quality outcomes (4)
36. Students' academic performance improved	QU2	
37. Teachers' teaching satisfaction in implementing e-learning for HOTS increased	QU3	
38. Qualities of schools in varies aspects improved	QU4	

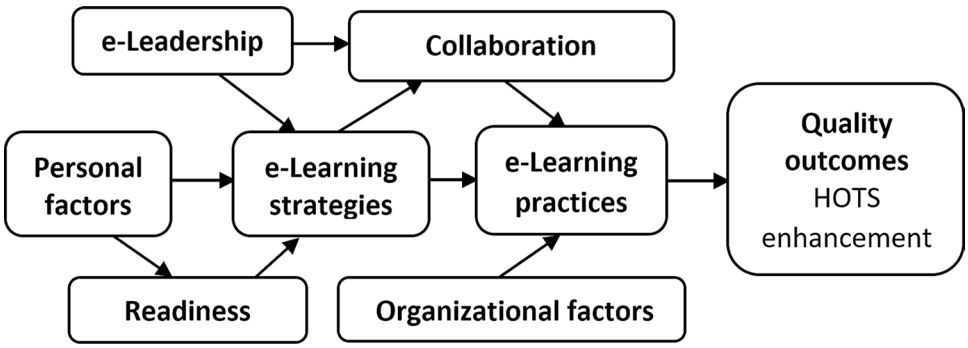

Fig. 1 The associations between the variables were generated from the selective coding approach and semantics relations method

were randomly selected as the sample for the quantitative study. Using teachers as participants has advantages because teachers implement e-learning platforms, assess the progress and behaviors of students in e-learning, and they also act as mediators between school principals, students and parents in e-learning platforms.

Since the data for this study were analyzed using PLS-SEM, the sample size was determined using the Sample Size Determination method for SEM Models [41]. With a small effect size of 0.2, desired statistical power of 0.80, eight latent variables, 38 observed variables, and a probability level of 0.05, the required sample size was calculated to be 444. This meets the minimum sample size requirement of 382, as determined by Krejcie and Morgan [30] for a population of 5,600.

A *proportional stratified random sampling procedure* was used to select 444 teachers from the four schools. The formula used to calculate the sub-sample size in each school is: (*The number of teachers in the school / Total number of teachers in the four schools)* × *Sample size*. After determining the sample, the questionnaire was then administered to the randomly selected teachers. These teachers serve as both instructors and practitioners of e-learning platforms in their schools. Inclusion criteria include teachers who are currently teaching in secondary schools using e-learning platforms, have at least one year of e-learning experience, and regularly integrate e-learning tools into their instruction. Exclusion criteria include teachers with less than one year of e-learning experience or those who use e-learning less than twice a week. Twenty-four teachers did not meet the inclusion criteria, resulting in 420 complete questionnaires being successfully collected, yielding a rate of 95%. The teachers had an average age of 39.2 years.

3.2.2 Survey questionnaire

The survey questionnaire utilized in this study was divided into two sections: one focusing on demographic variables and the other addressing eight key variables in the model developed from interview data.

The questionnaire comprised a total of 38 items, which were derived from the themes identified during the semi-structured interviews, as detailed in Table 1. For instance, the first item related to Collaboration (CO1) states, "*Design collaborative e-learning curriculum-related activities for fostering HOTS*." The questionnaire utilized a continuous measurement scale ranging from 0 to 10, where "0" represented "completely disagree" and "10" indicated "completely agree" with each statement related to enhancing higher order thinking skills through e-learning. This scale was selected for its precision, allowing for mathematical operations essential for PLS-SEM analysis [24]. Cohen, et al. [9] suggested using a continuous 0 to 10 interval scale for confirmatory factor analysis to establish validity and reliability of the items, while Awang [3] supported the use of an 11-point scale, which meets the requirements for ratio measures, ensuring valid and reliable statistical analysis.

The items were validated by three experts in educational psychology research. Thereafter a pilot study involved 100 respondents who did not participate in the actual study was conducted. Their responses were analyzed using *exploratory factor analysis* (EFA) to organize the items into constructs. Employing principal component analysis with varimax rotations, the 38 items were arranged into the eight constructs. Additionally, internal consistency reliability analysis was conducted, revealing high reliability coefficients for the constructs (Cronbach's alpha: collaboration = 0.82, readiness = 0.89, e-leadership = 0.87, personal factors = 0.91, strategies = 0.89, practices = 0.85, organizational factors = 0.85, and quality outcomes = 0.84).

3.2.3 Quantitative data analysis

Data analysis for the quantitative study was conducted with PLS-SEM using SMARTPLS 4 for: (1) confirmatory factor analysis (CFA), (2) model fit analysis, and (3) combined importance performance map analysis (cIPMA). CFA was used to examine the validity and reliability of the items of the eight variables; Model fit analysis was used to identify whether the relationships between the variables in the model are valid, and to determine whether further analysis is needed. The cIPMA was used to assess the importance and performance of the eight variables as necessary conditions for enhancing HOTS through e-learning.

4 Results

4.1 Confirmatory factor analysis

Confirmatory factor analysis (CFA) was conducted using *PLS-SEM algorithm* to assess convergent validity, construct validity, construct reliability, discriminant validity, and multicollinearity of the eight measurement models to ensure the items accurately represented the model's constructs. The results show that all indicator loadings met the benchmark of convergent validity (loadings ≥ 0.70). Besides that, construct validity (see Table 3: AVE > 0.50, ranging from

Table 3 Construct reliability and construct validity

	Construct reliability		Construct validity
	Cronbach's alpha	Composite reliability	Average variance extracted (AVE)
Quality outcome	0.85	0.85	0.54
Readiness	0.82	0.82	0.64
Personal factors	0.91	0.91	0.68
Collaboration	0.82	0.82	0.51
E-Learning Practices	0.84	0.85	0.58
E-Learning Strategies	0.89	0.89	0.60
E-leadership	0.87	0.87	0.59
Organizational factors	0.85	0.85	0.59

0.51 to 0.68) and construct reliability (Cronbach's alpha and composite reliability > 0.70, ranging from 0.82 to 0.91) were achieved for all the eight reflective measurement models.

Discriminant validity analysis was then conducted. HTMT assesses the true correlations between the measurement models. It is a reliable tool for assessing discriminant validity [24]. In this case, discriminant validity achieved in which no overlapping of concepts was found between the eight measurement models, with HTMT values < 0.90, ranging from 0.25 to 0.74 (see Table 4). The results ascertained that discriminant validity was achieved for all eight measurement models.

Furthermore, collinearity analysis was conducted to assess whether multi-collinearity occurs among the indicators in each measurement model. The results show that multicollinearity did not occur among all indicators in each of the eight measurement models, with VIF values < 5.0, ranging from 2.11 to 4.19.

4.2 Model fit

Model fit analysis was then analyzed to examine whether the relationships in the model are valid, that is, whether the model fits the data collected from sample of the study. The results show in Table 5 that model fit was confirmed, with SRMR = 0.06, D ULS = 0.34, D G = 1.23 and NFI = 0.91.

Table 4 Heterotrait-monotrait Ratio (HTMT)

	1	2	3	4	5	6	7
1. Collaboration							
2. E-Learning Practices	0.59						
3. E-Learning Strategies	0.54	0.65					
4. E-leadership	0.69	0.55	0.57				
5. Organizational factors	0.71	0.64	0.55	0.61			
6. Personal factors	0.40	0.51	0.44	0.36	0.53		
7. Quality outcome	0.47	0.51	0.50	0.67	0.40	0.26	
8. Readiness	0.67	0.50	0.57	0.74	0.60	0.25	0.52

Table 5 Model fit indices and the results of model fit testing

Model fit indices	Benchmarks	Estimated model	Model fit testing
SRMR	≤ 0.08	0.06	Model fit achieved
D ULS	≥ 0.05	0.34	Model fit achieved
D G	≥ 0.05	1.23	Model fit achieved
NFI	≥ 0.90	0.91	Model fit achieved

Model fit indexes were generated using PLS-SEM in SMARTPLS 4

4.3 Effects between the variables in the model

After confirming that all indicators of the eight measurement models met the requirements for construct validity, construct reliability, and discriminant validity; that there was no multicollinearity between the models or among the indicators; and that model fit was achieved, a PLS-SEM bootstrapping analysis was conducted to examine the relationships between the variables. The results in Fig. 2 show that all path coefficients in the model were significant ($p < 0.01$), thereby validating the findings of the qualitative study.

The final model depicted in Fig. 2 consists of the quality outcome for HOTS enhancement variable with its seven interrelated core factors. Quality outcome is directly influenced by e-learning practices, where a one-unit change in e-learning practices would cause a 0 514-unit increase or 26.4% of variance change in quality outcome ($\beta = 0.514$, $p < 0.01$; $R^2 = 0.264$).

Furthermore, e-learning practices play the role of a full mediator in creating the indirect effects of its three core factors, namely, e-learning strategies, organizational factors and collaboration on quality outcome. This means with right e-learning strategies ($\beta = 0.422$, $p < 0.01$), positive organizational factors ($\beta = 0.252$, $p < 0.01$) and excellent collaboration between the stakeholders ($\beta = 0.212$, $p < 0.05$), e-learning practices would be maximized to nearly 53.4% ($R^2 = 0.534$, large effect size).

In addition, e-learning strategies also has three direct factors, namely, e-leadership ($\beta = 0.208$, $p < 0.01$), personal factors ($\beta = 0.271$, $p < 0.01$) and readiness ($\beta = 0.384$, $p < 0.01$), where readiness plays the main role, followed by personal factors and e-leadership, and the three factors contribute 42.2% of e-learning strategies ($R^2 = 0.422$, large effect size). This means to improve e-learning strategies, readiness of schools, teachers and students for enhancing HOTS through e-learning, personal factors, and e-leadership of school leaders in enhancing HOTS through e-learning are needed to maximize e-learning strategies and to stimulate a conducive culture.

The following are five sub-models derived from the results in Fig. 2. These sub-models are the basics of the *e-learning HOTS enhancement* model. The sub-models serve as useful guides for improving higher order thinking skills in schools through e-learning platforms.

Sub-model 1:

Quality outcome—HOTS enhancement = 0.514 E-learning practices.

$R^2 = 0.264$ (large effect).

Sub-model 2:

E-learning practices = 0.422 E-learning strategies + 0.252 Organizational factors + 0.212 Collaboration.

$R^2 = 0.534$ (large effect).

Sub-model 3:

E-learning strategies = 0.384 Readiness + 0.271 Personal factors + 0.208 E-leadership.

$R^2 = 0.422$ (large effect).

Sub-model 4:

Collaboration = 0.524 E-leadership + 0.283 E-learning strategies.

$R^2 = 0.466$ (large effect).

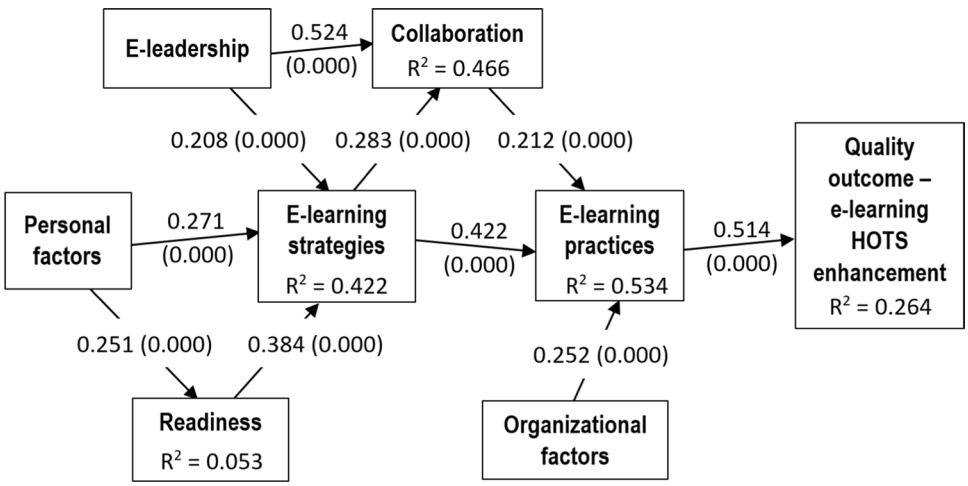

Fig. 2 The results of the quantitative study support the e-learning HOTS enhancement model generated from the qualitative study

Table 6 cIPMA results for e-learning HOTS enhancement

Antecedent constructs	Importance	Performance	Percentage of cases that do not meet the necessary condition[a]	Accuracy	CR-FDH Necessity effect size (*p* value)
Collaboration	0.11	44.61	26.47	99.81	0.16 (0.000)
E-Learning Practices	0.51	42.05	31.53	99.25	0.15 (0.000)
E-Learning Strategies	0.25	39.00	34.21	98.87	0.16 (0.000)
E-leadership	0.10	31.00	41.30	99.06	0.17 (0.000)
Organizational factors	0.12	45.87	25.88	99.44	0.11 (0.007)
Personal factors	0.08	51.89	27.95	99.06	0.11 (0.104)
Readiness	0.10	37.47	19.98	99.44	0.08 (0.009)

[a]Based on a desired HOTS enhancement outcome level of 80%

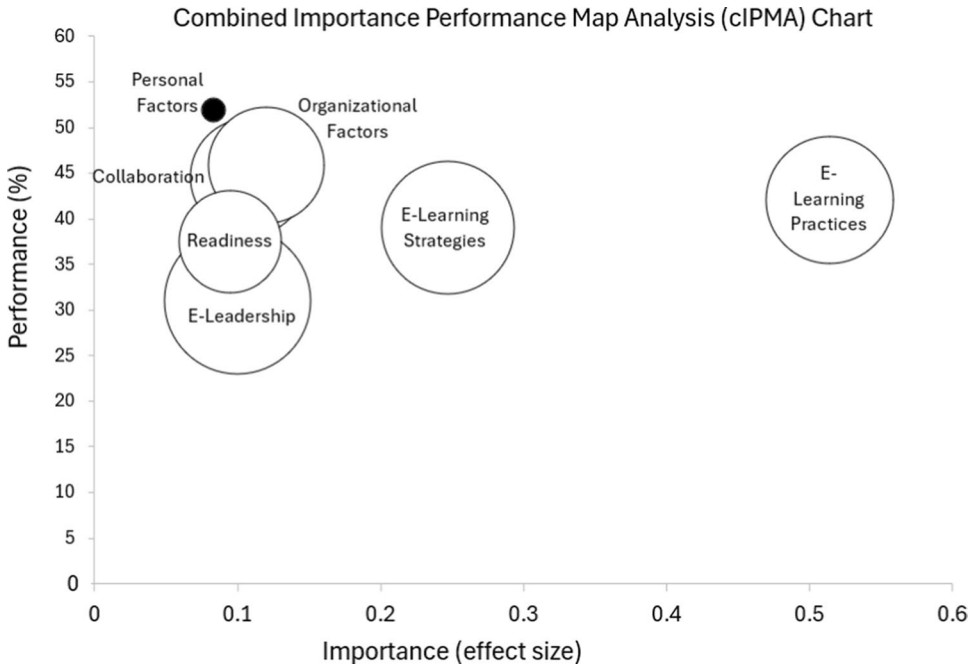

Fig. 3 Combined importance performance map analysis on e-learning HOTS enhancement

Sub-model 5:

Readiness = 0.251 Personal factors.

$R^2 = 0.053$ (small effect).

Note: Effect sizes for social science data: R^2: 0.01 = small effect, 0.09 = medium effect, 0.25 = large effect [22].

After the model was finalized, the next steps were to assess the importance, performances and the levels of the necessary conditions that needed to maximize e-learning HOTS enhancement.

4.4 Combined importance and performance map analysis

The combined importance–performance map analysis (cIPMA) presents the necessary condition analysis outputs [14] within an importance–performance map [26, 40] (see Table 6 and Fig. 3). It facilitates better prioritization of management actions [26], aimed at enhancing HOTS in e-learning. In Fig. 3, factors that are not necessary for achieving the desired 80% performance level of HOTS enhancement are shown as small black circles, while necessary factors are represented by white circles. The size of the white circles indicates the percentage of cases that fail to meet the required levels to attain the desired 80% performance benchmark [40] for e-learning HOTS enhancement. The cIPMA results in Table 6 show that six of the seven factors, represented by white circles in Fig. 3, are identified as significant necessary conditions: collaboration ($d = 0.13$, $p < 0.001$), e-learning practices ($d = 0.15$, $p < 0.001$), e-learning strategies ($d = 0.16$, $p < 0.001$), e-leadership

(d = 0.17, p < 0.001), organizational factors (d = 0.11, p < 0.01), and readiness (d = 0.08, p < 0.01). In contrast, personal factors are not considered a necessary condition (d = 0.11, p > 0.05).

Table 6 indicates that e-learning practices are highly important, yet nearly one-third or 31.53% of respondents did not reach the required level to achieve the desired 80% performance of HOTS enhancement. The second important factor, e-learning strategies, had 34.21% of respondents falling short of the desired target. E-leadership, represented by the largest white circle, is a critical necessary condition, with more than 40 percent of the respondents (41.30%) not meeting the required threshold. This would significantly hinder efforts to enhance HOTS to at least 80% level.

Additionally, there were two necessary conditions, organizational factors (25.88%) and readiness (19.98%) that have less than 30% of respondents failing to meet the required levels. Consequently, in the context of e-learning HOTS enhancement, the two factors should receive relatively lower priority compared to e-leadership, e-learning practices, and e-learning strategies.

The cIPMA bottleneck table (Table 7) presents the percentage of respondents who did not meet the required level of each necessary condition for achieving the desired 80% performance level of e-learning HOTS enhancement.

5 Discussion

The e-learning HOTS enhancement model generated from the study has a limited scope and is not intended to establish a universal standard. However, it can serve as a reference for schools using e-learning platforms to enhance e-leadership practices for higher order thinking skills enhancement. Practically, this research offers a framework that educational leaders, policymakers, and educators can adopt to enhance HOTS in e-learning. Schools can leverage findings on e-learning strategy and practices, collaboration, organizational factors, readiness, and e-leadership to design programs and policies that encourage higher order thinking skills in e-learning. Training programs for teachers and administrators can focus on e-leadership and innovative e-learning strategies, ensuring institutional support and structured development of HOTS. Additionally, the research highlights the importance of creating supportive policies

Table 7 cIPMA bottleneck table for e-learning HOTS enhancement

HOTS enhancement	Collaboration	E-Learning Practices	E-Learning Strategies	E-leadership	Organizational factors	Readiness
0%	NN	NN	NN	NN	NN	NN
5%	NN	NN	NN	NN	NN	NN
10%	NN	NN	NN	NN	NN	NN
15%	NN	NN	NN	NN	NN	NN
20%	NN	NN	NN	NN	NN	NN
25%	NN	NN	NN	NN	NN	NN
30%	NN	NN	NN	NN	NN	NN
35%	0.452	1.771	0.582	NN	NN	NN
40%	3.342	5.078	4.318	NN	NN	NN
45%	6.233	8.385	8.054	NN	NN	NN
50%	9.123	11.691	11.791	NN	3.148	NN
55%	12.014	14.998	15.527	NN	6.937	NN
60%	14.905	18.305	19.264	5.937	10.726	3.528
65%	17.795	21.611	23.000	14.778	14.516	7.642
70%	20.686	24.918	26.737	23.619	18.305	11.756
75%	23.576	28.225	30.473	32.460	22.094	15.870
80%	26.467	31.531	34.210	41.302	25.884	19.984
85%	29.357	34.838	37.946	50.143	29.673	24.098
90%	32.248	38.145	41.683	58.984	33.463	28.212
95%	35.138	41.452	45.419	67.825	37.252	32.326
100%	38.029	44.758	49.156	76.666	41.041	36.440

NN = not necessary

and partnerships with external organizations, which can provide resources and expertise to overcome e-learning obstacles.

The study contributes to existing theories by expanding on the *Community of Inquiry* model [19], which focuses on cognitive, social, and teaching presence, but neglects institutional and e-leadership factors critical for successful e-learning. It accomplishes the existing models like *TPACK* [32], *SAMR* [37], *PTEACES* [28] and TAM [13] by addressing personal, organizational and collaboration factors. Integrating these factors provides a more holistic model for developing HOTS in e-learning. By addressing these additional factors, this model fills theoretical gaps in understanding the key factors and their relationships for enhancing HOTS in e-learning platforms.

Five sub-models emerged from the data, defining the model of HOTS enhancement through e-learning in schools.

1. To maximize the quality of e-learning HOTS enhancement, schools should maximize the use of discussions and forums to enhance HOTS, incorporate multiple simulations in e-learning platforms to develop HOTS, use varied assessment methods focusing on HOTS, apply continuous assessments in e-learning practices for HOTS enhancement, and share best e-learning practices for developing HOTS among teachers (refer to Sub-model 1).

2. To maximize e-learning practices for HOTS enhancement, schools should implement effective e-learning strategies that include using inquiry-based approaches in e-learning to foster higher-order thinking skills, accepting different views in e-learning to enhance HOTS, integrating creative multimedia resources in e-learning to enhance HOTS, and developing interdisciplinary e-learning projects focusing on HOTS. Besides that, in terms of organizational factors, schools should provide sufficient technical support for improving HOTS in e-learning, provide sufficient institutional backing for professional development focused on HOTS, provide HOTS online resources for teachers, cultivate community engagement to support HOTS initiatives, implement supportive policies from educational authorities to promote HOTS among students, and develop partnerships with external organizations that facilitate students' HOTS development. Furthermore, schools must try to maximize collaboration between stakeholders, including maximizing feedback loops to promote HOTS in students, designing group problem-based e-learning projects that enhance HOTS, designing collaborative e-learning curriculum-related activities for fostering HOTS, and establishing e-learning working committees focused on HOTS (refer to Sub-model 2).

3. To maximize e-learning strategies for HOTS enhancement, schools must ensure that the readiness of schools, their e-learning facilities, and their stakeholders are at the highest levels by implementing the following: enhancing students' knowledge of HOTS in e-learning, regularly evaluating school technology infrastructures for HOTS enhancement, creating school policies that promote HOTS through e-learning, implementing training courses focused on fostering HOTS, encouraging mindset changes among students, teachers, and school administrators, and cultivating a positive attitude among students, teachers, and school administrators towards e-learning. Besides that, schools must consider personal factors, including promoting positive attitudes through interactive HOTS activities, addressing students' needs related to HOTS development, encouraging students' involvement in HOTS participation, fostering teachers' commitment to e-learning platforms that promote a culture of higher-order thinking skills, and encouraging HOTS through self-directed e-learning among students. Finally, e-leadership in schools should be maximized by providing e-leadership training for administrators and teachers to improve their knowledge of enhancing HOTS through e-learning, encouraging innovative practices to foster HOTS, developing a mission and vision for integrating HOTS into e-learning, and promoting leadership initiatives that support HOTS (refer to Sub-model 3).

4. To maximize collaboration between stakeholders, e-leadership should be implemented to its maximum by developing a mission and vision for integrating HOTS into e-learning, providing e-leadership training, promoting leadership initiatives that support HOTS, and encouraging innovative practices to foster HOTS. Besides that, schools should implement the following e-learning strategies: integrating creative multimedia resources in e-learning to enhance HOTS, using inquiry-based approaches in e-learning to foster HOTS, accepting different views in e-learning to enhance HOTS, and developing interdisciplinary e-learning projects focusing on HOTS (refer to Sub-model 4).

5. To effectively enhance e-learning readiness, schools, teachers, and parents must fully consider students' needs related to HOTS development, promote positive attitudes through interactive HOTS activities, encourage students' involvement in HOTS participation, foster teachers' commitment to e-learning platforms that cultivate a culture of HOTS, and encourage HOTS through self-directed e-learning among students (refer to Sub-model 5).

An interesting and significant finding is that e-leadership is a critical necessary condition, with more than forty percent of the respondents not meeting its required threshold to achieve 80% of e-learning HOTS enhancement. This underscores the vital roles of school leaders and teachers in guiding the e-learning community toward the enhancement of HOTS through e-learning. Nevertheless, the results suggested that all the six necessary conditions are directly

or indirectly interrelated, and none of them can be ignored in maximizing HOTS among students in e-learning. HOTS enhancement will not reach its maximum if one of the six necessary factors is not achieved.

6 Implications of the study

This study contributes theoretically by expanding existing e-learning models, highlighting that human and organizational factors, e-leadership, collaboration, and readiness are essential for enhancing HOTS among students in e-learning. It addresses the limitations in existing e-learning models like SAMR, TPACK, PTEACES, and TAM, which focus mainly on technology use rather than cognitive development. Practically, the new model offers school leaders, policymakers, and educators a structured guide to foster HOTS through addressing and enhancing practices, strategies, collaboration, leadership, readiness and organizational factors in e-learning platforms.

7 Conclusion

This research provides a comprehensive picture for enhancing higher order thinking skills among students in e-learning platforms. E-learning practices, e-learning strategies, collaboration, e-leadership, organizational factors and readiness emerged as essential necessary conditions for fostering HOTS. This study provides an actionable model for enhancing HOTS in secondary schools. Future research could explore the application of this model in other educational contexts to validate its adaptability and effectiveness in diverse educational settings.

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Data availability The datasets of the current study are not publicly available due to funding restrictions but may be available upon reasonable request.

Declarations

Ethics approval and consent to participate This study was ethically approved for its general characteristics the Ethics Committee of the University of Malaya, Malaysia. All methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication Informed consent was obtained from all individual participants included in the study.

Competing interests The authors declare no competing interests.

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