The Impact of Cognitive Strategies on Critical Thinking in Chinese Female Pre-Service Teachers' Smart Learning

Abstract

This study examines the impact of Constructivist Smart Learning Environments (CSLE) and cognitive strategies on the development of Higher-Order Thinking Skills (HOTS). While CSLEs are widely recognized for fostering advanced competencies in higher education, the specific structural mechanisms—particularly whether cognitive strategies act as direct predictors or mediating pathways linking multidimensional smart environments to HOTS—remain underexplored. Using a quantitative cross-sectional design, data were collected from 686 female pre-service teachers across four universities in Shanxi Province, China. Structural Equation Modeling revealed significant positive relationships between smart learning environment dimensions and HOTS. Specifically, inquiry learning, reflective thinking, and perceived usefulness exerted substantial direct effects. Crucially, cognitive strategies fully mediated the impacts of inquiry learning and reflective thinking on HOTS, while partially mediating the effect of perceived usefulness. These findings clarify the underlying psychological mechanisms operating within CSLEs, demonstrating that technological and constructivist affordances enhance HOTS primarily by activating high-level cognitive strategies. This study provides critical theoretical and practical insights for designing smart pedagogical environments in pre-service teacher education.

Keywords

Higher-Order Thinking Skills; Cognitive Strategies; Constructivist Smart Learning Environments

1. Introduction

Higher-order thinking skills (HOTS) encompass critical thinking, problem-solving, and creative thinking, which are pivotal for students' success and learning in the 21st century (Marwan et al., 2021). These competencies have become central competencies in international educational frameworks (Preus, 2012). In China, increasing emphasis has been placed on cultivating HOTS in higher education is evident (Ministry of Education, 2021). Notably, the issuance of "The Implementation of Outstanding The Teacher Training Plan 2.0' issued by the Chinese Ministry of Education in 2020 underscores the urgent need to cultivate high-quality pre-service teachers equipped with

HOTS (Liu et al., 2021). Developing HOTS is particularly crucial for pre-service teachers because their professional mandate is dual-faceted: they must not only master complex problem-solving, critical analysis, and creative thinking themselves, but also possess the pedagogical competence to model and actively cultivate these competencies in their future students.

A Constructivist Smart Learning Environments (CSLE), designed with learners at the core, prioritizes their active role in knowledge construction (Rosmansyah et al., 2022). By blending physical and virtual realms and integrating advanced educational technology, it facilitates easy, engaging, and effective learning experiences that are accessible anytime, anywhere, and at any pace (Agbo et al., 2020; Murthy et al., 2016; Spector, 2014). Smart learning classrooms are increasingly regarded as an effective approach for fostering HOTS in fostering students' HOTS and are gaining traction within higher education institutions in China (Zhang et al., 2021). Smart learning classrooms are increasingly adopted across Chinese higher education institutions to foster students' HOTS. Theoretically, these environments enhance higher-order competencies by integrating smart technological affordances with constructivist pedagogical designs—enabling authentic problem-solving, real-time cognitive scaffolding, and continuous collaborative inquiry that shift students from rote memorization toward deep, critical, and reflective thinking

Nonetheless, recent studies reveal that the HOTS levels of Chinese college students, including pre-service teachers, remain at an intermediate stage (Zhong, 2017). This suggests that efforts to teach HOTS among pre-service teachers have not yielded the desired outcomes in China. However, the technological affordances of smart learning environments alone do not guarantee the development of HOTS, fostering active, autonomous, and independent knowledge construction, personal factors such as learning strategies and motivation are crucial influencers (Zhang et al., 2021). Therefore, understanding how learners' cognitive strategies interact with CSLEs has become an important research priority.

However, the traditional teacher-centered approach, reliant on lectures, often overlooks the impact of students' attributes, leading to suboptimal outcomes (Gao, 2022). Conventional instructional models rely heavily on passive knowledge transmission, a structure that restricts students to basic recall and comprehension while neglecting the analytical, evaluative, and creative dimensions intrinsic to HOTS. To address this deficit, CSLEs are designed to reposition learners as active knowledge builders. However, this pedagogical paradigm shift presents substantial operational hurdles. Many educators encounter significant challenges in relinquishing traditional instructor-led roles and adopting the student-centered, technology-mediated facilitation required in CSLEs, which in turn limits the full realization of students' higher-order cognitive potential (Gao, 2022). The endeavor to teach HOTS in smart classrooms is still in its nascent and exploratory phase in China, necessitating relevant theories and information to guide educators (Liu et al., 2021)

Previous studies consistently highlight the importance of learning environment, motivation, and cognitive factors in shaping learners' information processing, thereby influence a range of learning outcomes, including higher-level thinking (Kwan & Wong, 2015). Linnenbrink and Pintrich (2000) assert that students' learning outcomes predominantly stem from their motivational and cognitive factors (Kwan & Wong, 2015). Prior research underscores the pivotal role of cognitive strategies and goal orientation as predictors of academic performance and learning outcomes.

Cognitive and metacognitive strategies represent distinct pillars of self-regulated learning. While metacognitive strategies involve the higher-level regulation, monitoring, and planning of the learning process, cognitive strategies—the explicit focus of this study—refer to the direct mental operations, such as elaboration, organization, and critical structuring, used to actively process and integrate new information. By narrowing our scope to these cognitive mechanisms, this study identifies the specific information-processing pathways through which CSLE catalyze the development of HOTS. Some studies showed that different learning environments, in conjunction with students' cognitive strategies, yield varying effects on thinking outcomes (Kwan & Wong, 2015).

To address the disconnect between technological adoption and cognitive development, this study fills a critical research gap: while CSLEs are widely implemented, the underlying psychological mechanisms explaining how they effectively cultivate HOTS remain opaque. We address this by proposing and validating a structural model that positions cognitive strategies as the essential mediating pathway between CSLE affordances and HOTS. Theoretically, this study extends the existing literature on constructivist learning by shifting the discourse from a focus on environmental features alone to the cognitive processes they trigger, thereby elucidating the specific psychological ‘black box’ of smart learning. Practically, these findings provide a robust framework for Chinese pre-service teacher education programs, offering empirical guidance for curriculum designers to prioritize the promotion of high-level cognitive strategies, directly supporting the pedagogical goals mandated by the ‘Teacher Training Plan 2.0.

2. Literature Review

2.1 Fostering Knowledge Construction and HOTS in CSLEs

At the core of constructivism, learning is the active process of knowledge construction, where learners reconcile cognitive conflicts and satisfy curiosity through assimilation and adaptation (Bada & Olusegun, 2015). The development of HOTS is inextricably linked to the depth of this construction; the cognitive actions required—manipulation, evaluation, and critical reflection—constitute the very essence of HOTS. Consequently, environments demanding active knowledge construction transform learners from passive processors into critical thinkers through authentic problem-solving (Ibnu & Rahayu, 2020).

Research indicates that conducive environments, particularly those perceived positively by students, foster deep learning strategies and profound outcomes (Kaniaswari & Suzianti, 2020). The CSLE represents a novel paradigm, utilizing advanced technologies to provide seamless connectivity, agile perception, and adaptive services (Javed, 2025). These functionalities facilitate flexible, participatory experiences that, when paired with effective instruction, drive higher-level cognitive engagement (Spector, 2014). Based on these theoretical foundations, we hypothesize that significant positive relationships exist between the key components of CSLEs and the HOTS of Chinese pre-service teachers.

2.2 The mediating effect of Cognitive Strategies on CSLE and HOTS

Cognitive strategies are the mental processes learners employ to obtain, transform, retain, and utilize information to achieve specific goals (Prayogi & Verawati, 2020). They encompass identifying, encoding, and organizing externally acquired information, alongside systematically storing processed data. Previous research consistently demonstrates that learning environment factors positively predict learning strategies, which in turn directly influence higher-order thinking skills (HOTS) across diverse settings (Bada & Olusegun, 2015).

While metacognitive strategies are theoretically intertwined with cognitive strategies—enabling students to monitor and optimize their approach—this study prioritizes model parsimony (Sortwell et al., 2026). To avoid multicollinearity and maintain a focused analysis of causal mechanisms, metacognitive strategies were excluded from the current conceptual design. Empirical evidence from technology-mediated contexts supports the pivotal role of learning strategies in developing HOTS. For instance, Lu et al. (2021) demonstrated that in blended and flipped learning environments, strategies such as guided inquiry and concept mapping significantly enhance critical thinking, problem-solving, and creativity. Although these studies focused on conventional configurations, they provide a vital baseline for understanding how student-centered, technology-supported strategies foster HOTS within more adaptive, data-driven smart contexts. Furthermore, Kwan and Wong (2015) found that cognitive strategies fully mediate the relationship between constructivist environments and critical thinking, suggesting that constructivist features foster HOTS indirectly by encouraging learners to organize, elaborate, and integrate knowledge.

In CSLEs, this mediating mechanism is theoretically plausible due to the interplay between constructivist pedagogy and smart technological affordances (Churchill & Churchill, 2008). Rather than replacing cognition, CSLE features—such as adaptive scaffolding, real-time analytics, and data-driven personalization—act as external catalysts that prompt and sustain deep cognitive operations like organizing and critical evaluation. Consequently, cognitive strategies are hypothesized to serve as the essential psychological bridge through which the technological and pedagogical features of a CSLE are translated into HOTS (Ruzaman & Rosli, 2020).

3. Methodology

3.1 Research design

A cross-sectional survey design was employed in this study for data collection in which all variables are measured at the same time point. The collected data were subsequently analyzed and interpreted to examine the relationships between the variables. According to Creswell and Creswell (2017), in quantitative research, research questions are always specific, measurable, and observable based on trends or a need for an explanation of the relationship among variables.

3.2 Sampling

The target population comprised female pre-service teachers at four public normal universities in Shanxi, China. Based on Cochran's formula, a baseline of 385 participants was established. To satisfy Structural Equation Modeling (SEM) requirements—specifically the 10–20 observations per parameter rule (Kline, 2023), 2023)—the sample was expanded to 725. This exceeds the 200–400 threshold for stable maximum likelihood estimation (Hair et al., 2024) and ensures sufficient power ($1-\beta>0.801$) to detect small-to-medium effect sizes.

A multi-stage, proportional stratified random sampling method was employed (Hair Jr et al., 2018). The sample was proportionally allocated across the four universities, then stratified by academic field and year of study. Within each "university ×\times× field ×\times× year" stratum, participants were selected via computer-generated random sequences from official rosters. This procedure ensured every eligible student had an equal probability of selection, minimizing bias and enhancing the external validity and generalizability of the findings.

3.3 Measurement

The survey instrument employed in this study comprised two primary sections: (1) demographic characteristics of the participants (e.g., gender, grade level, academic discipline), and (2) validated measurement scales operationalizing the four core theoretical constructs in our structural model. To ensure measurement consistency and psychometric rigor, all adopted scales used a 5-point Likert response format ranging from 1 (*"Strongly Disagree"*) to 5 (*"Strongly Agree"*). The instruments were organized as follows:

CSLE: erceptions of the smart learning environment were assessed using the *Instrument of Constructivist Smart Learning Environments (I-CSLE)*, originally developed by MacLeod et al. (2018) and validated in Chinese higher-education contexts (e.g., Wong et al., (2006)). The instrument comprises 40 items across eight sub-dimensions (5 items each), rated on a 5-point Likert scale from 1 (*"strongly disagree"*) to 5 (*"strongly agree"*): (1) *Student Negotiation* ($\alpha=0.89$, e.g., peer discussions on investigative methods), (2) *Inquiry Learning* (α=0.86, e.g., undertaking follow-up inquiries to address new questions), (3) *Reflective Thinking* (α=0.91, e.g., deep contemplation on one's own learning process), (4) *Functional Design* (α=0.81, e.g., adequacy of physical/virtual space for group dialogues), (5) *Connectedness* (α=0.86, e.g., interpersonal connection with instructors and peers), (6) *Ease of Use* (α=0.88, e.g., intuitive technological navigation), (7) *Perceived Usefulness* (α=0.89, e.g., technological enhancement of learning experiences), and (8) *Multiple Sources* (α=0.83, e.g., access to diverse information resources improvements made:

1. **Resolved author conflicts:** Seamlessly integrated MacLeod et al. (2018), Churchill et al. (2008), and Ma et al. (2019) into one coherent developmental lineage.
2. **Eliminated wordiness:** Condensed repetitive opening phrases ("In the smart classroom, I can…") into succinct parenthetical descriptions while preserving all Cronbach's α\alphaα values and item counts (total = 40 items).
3. **Fixed typos:** Corrected grammatical lapses (e.g., *"Chinese cotect"*, *"supporteffective"*, *"explore of varied"*).

Cognitive and Metacognitive Strategies & Goal Orientations: These constructs were operationalized using subscales adapted from the *Motivated Strategies for Learning Questionnaire (MSLQ)* (Pintrich, 2000), a widely validated instrument for assessing motivational orientations and learning tactics in higher education (Zhang et al., 2021). All items were rated on a 5-point Likert scale ranging from 1 (*"strongly disagree"*) to 5 (*"strongly agree"*).

1. **Cognitive and Metacognitive Strategies:** To capture the depth of internal information processing and regulatory processes, four specific subscales were employed: (a) *Rehearsal* (α=0.91, 4 items; e.g., committing key terms to memory), (b) *Elaboration* (α=0.91, 6 items), (c) *Organization* (α=0.92, 4 items), and (d) *Metacognitive Self-Regulation* (α=0.89, 12 items; e.g., adapting study methods to course requirements). These strategies are recognized as potent predictors of higher-order thinking in constructivist environments (Zhang et al., 2021).
2. **Goal Orientations:** To assess students' motivational drivers and intentions within the smart learning context, the *Intrinsic Goal Orientation* and *Extrinsic*

Goal Orientation subscales were utilized. These scales measure the degree to which learners are driven by mastery-based interests versus performance-based external rewards.

Chinese College Students High Order Thinking Skill Test Scale (CCS-HOTS): Higher-order thinking was assessed using the *Chinese College Students' HOTS Scale (CCS-HOTS)* (Lu et al., 2021), a 20-item instrument originally developed for technology-supported learning in Chinese higher education. Although initially framed within mobile learning contexts, the CCS-HOTS is theoretically aligned with CSLEs because both settings leverage ubiquitous digital affordances, interactive problem-solving tasks, and self-directed inquiry to foster high-level cognition. The scale measures three core dimensions on a 5-point Likert scale (1 = *"strongly disagree"* to 5 = *"strongly agree"*): (1) *Critical Thinking Skills* (α=0.91, 6 items; e.g., actively seeking supporting evidence for theories), (2) *Problem-Solving Skills* (α=0.89, 10 items; e.g., articulating problem-solving methodologies), and (3) *Creative Thinking Skills* (α=0.88, 4 items; e.g., iteratively refining study plans and validating novel approaches). In the present study, confirmatory factor analysis (CFA) further supported the scale's construct validity and structural robustness within the smart classroom context.

In this study, all of these instruments are adapted from established scales of Chinese revisions and have been revised and translated by some experts and scholars with high academic levels in related professional fields, and have demonstrated acceptable reliability and validity indicating acceptable reliability and validity.

3.4 Data Analysis

Data were analyzed using variance-based Partial Least Squares Structural Equation Modeling (PLS-SEM) in SmartPLS (v.4) following a two-step analytical procedure (Hair et al., 2022). First, the measurement model was evaluated for reflective construct adequacy: indicator reliability was assessed via outer factor loadings (≥0.70), internal consistency reliability via Cronbach's α (≥0.70) and Composite Reliability (CR≥0.70), and convergent validity via Average Variance Extracted (AVE≥0.50). Discriminant validity was confirmed using the Fornell–Larcker criterion and the Heterotrait-Monotrait ratio (HTMT<0.85).

Second, the structural model and hypothesized mediation paths—linking the CSLE to HOTS through Cognitive Strategies—were assessed after confirming the absence of multicollinearity (VIF<3.3). Path significance was tested using a non-parametric bootstrapping procedure (5,000 resamples, 95% bias-corrected confidence intervals). Model explanatory and predictive power were evaluated using path coefficients (β), coefficients of determination (R^2), effect sizes (f^2), and Stone–Geisser's predictive relevance (Q^2).

4. Results

4.1 Demographic Profile of Respondents

Of 725 survey respondents, 39 were excluded due to missing data, straight-lining, or rapid completion (<1 minute), yielding 686 valid responses for PLS-SEM analysis. As detailed in Table 1, participants were evenly distributed across four universities (24.6%–25.2%). By academic year, most were freshmen (32.6%) and sophomores (29.4%), followed by juniors (20.4%) and seniors (17.6%). Regarding academic discipline, 65.2% studied social sciences, while 34.8% were in natural sciences.

Table 1. Profile of Respondents.

Personnel Characteristic	Demographic Variables	Frequency (n)	Percentage（%）
Institution	Shanxi Normal University	173	25.2
	Taiyuan Normal University	169	24.6
	Yuncheng Normal College	171	25.0
	Yuncheng College	173	25.2
Grade	Freshman	223	32.6
	Sophomore	202	29.4
	Junior	140	20.4
	Senior	121	17.6
Field	Social Science	447	65.2
	Science	239	34.8

4.2 The relationship between CSLE components and HOTS

This study aims to examinethe relationship between components of a CSLE and the development of HOTS in pre-service teachers in China. Specifically, the study seeks to examine the correlation between various sub-constructs of CSLEs (such as student negotiation, inquiry learning, reflective thinking, functional design, connectedness, ease of use, perceived usefulness, and multiple sources) and the enhancement of HOTS.

Eight hypotheses were tested using Pearson correlation analysis, as presented in Table 2.

Table 2. Pearson Correlation Test.

Variables	1	2	3	4	5	6	7	8	9	10
1. HOTS	1									
2. CS	.796**	1								
3. MS	.581**	.592**	1							
4. PU	.602**	.588**	.870**	1						
5. EU	.548**	.545**	.833**	.895**	1					
6. CN	.563**	.571**	.817**	.843**	.831**	1				
7. FD	.602**	.625**	.789**	.824**	.818**	.823**	1			
8. RT	.633**	.715**	.727**	.689**	.673**	.689**	.765**	1		
9. IL	.615**	.684**	.697**	.659**	.625**	.655**	.714**	.815**	1	
10. SN	.600**	.641**	.739**	.728**	.685**	.742**	.746**	.750**	.803**	1

Note: High Order Thinking Skills = HOTS, Cognitive strategies = CS, Multiple sources = MS, Perceived usefulness = PU, Ease of use = EU, Connectedness = CN, Functional design = FD, Reflective thinking = RT, Inquiry-based learning = IL, Student negotiation = SN. **. Correlation is significant at the 0.01 level (2-tailed).

The results from Table 2 indicate the strength of correlations between different sub-constructs of the learning environment and HOTS:

Inquiry learning exhibited a significant positive correlation of 0.61 ($p < .001$) with HOTS, thus supporting hypothesis H_{1b}. Reflective thinking demonstrated a substantial positive correlation of 0.63 (p=.01) with HOTS, providing support for hypothesis H_{1c}. The functional design showcased a notable positive correlation of 0.60 (p=.01) with HOTS, validating hypothesis H_{1d}. Connectedness displayed a meaningful positive correlation of 0.56 (p=.01) with HOTS, corroborating hypothesis H_{1e}. Ease of use revealed a significant positive correlation of 0.55 (p=.01) with HOTS, lending credence to hypothesis H_{1f}. Perceived usefulness demonstrated a considerable positive correlation of 0.60 (p=.01) with HOTS, affirming hypothesis H_{1g}. Multiple sources exhibited a substantial positive correlation of 0.58 (p=.01) with HOTS, substantiating hypothesis H_{1h}.

Overall, the preliminary bivariate correlation analyses revealed significant positive associations between all eight examined CSLE components and pre-service teachers' HOTS, providing initial alignment with our theoretical framework prior to formal structural model testing.

4.3 The mediating role of cognitive strategies on the relationships between eight components of CSLE and HOTS

The second aim of this study is to explore the mediating role of cognitive strategies in the association between the components of CSLEs and the cultivation of HOTS among pre-service teachers in China. This objective involved the formulation of eight research hypotheses (H_{2a}, H_2b, H_{2c}, H_{2d}, H_{2e}, H_{2f}, H_{2g}, H_{2h}). These hypotheses centered around the eight sub-constructs of CSLEs (namely, student negotiation, inquiry learning, reflective thinking, functional design, connectedness, ease of use, perceived usefulness, and multiple sources) as independent variables, and HOTS as the dependent variable. The purpose was to assess the mediating impact of cognitive strategies on the connections between these sub-constructs and HOTS. The mediation model was tested in SmartPLS using non-parametric bootstrapping with 5,000 resamples to generate 95% bias-corrected and accelerated (BCa) confidence intervals, as illustrated in Figure 1 and detailed in Table 3.

Table 3. Results of the mediating effects of CS on the relationships between eight sub-constructs of CSLE and HOTS.

Path	Path coefficient	T Statistics (|O/STDEV|)	P	2.50%	97.50 %
SN → HOTS	0.05	1.702	0.089	-0.008	0.111
IL →HOTS	0.035	0.941	0.347	-0.04	0.1
RT → HOTS	0.026	0.831	0.407	-0.039	0.086
FD → HOTS	0.019	0.584	0.56	-0.042	0.086
CN → HOTS	0.032	1.127	0.26	-0.021	0.09
EOU → HOTS	0.041	1.193	0.233	-0.025	0.101
PU → HOTS	0.052	1.247	0.213	-0.021	0.136
MS → HOTS	0.026	0.831	0.407	-0.039	0.086
SN→ CS → HOTS	0.037	0.825	0.41	-0.056	0.125
IL→ CS →HOTS	0.135	2.456	0.004	0.03	0.249
RT→CS → HOTS	0.214	4.154	0	0.107	0.309
FD → CS→ HOTS	0.059	1.12	0.263	-0.047	0.151
CN → EOU → HOTS	0.031	0.483	0.629	-0.158	0.097
EOU → CS → HOTS	0.133	1.877	0.061	-0.273	-0.001
PU → CS →HOTS	0.242	3.391	0.001	0.094	0.376
MS → CS →HOTS	0.023	0.33	0.741	-0.118	0.166

Note: High Order Thinking Skills = HOTS, Cognitive strategies = CS, Multiple sources = MS, Perceived usefulness = PU, Ease of use = EU, Connectedness = CN, Functional design = FD, Reflective thinking = RT, Inquiry-based learning = IL, Student negotiation = SN.

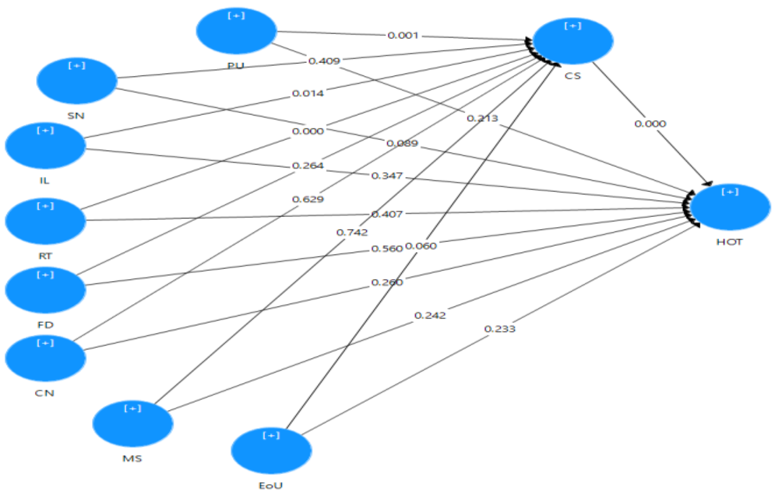

Figure 1. Mediation Model.

Results from Table 3 revealed the direct and indirect effects of cognitive strategies on the relationships between different sub-constructs of the learning environment and HOTS: Student negotiation had no significant direct effect (0.05, $p > .05$) or mediating effect (0.04, $p > .05$) on HOTS, thus not supporting hypothesis H2a. Inquiry learning displayed no noteworthy direct effect (0.04, $p > .05$) but exhibited a significant mediating effect (0.14, $p < .01$) of cognitive strategies on the relationship with HOTS, confirming hypothesis H_{2b}. Reflective thinking showed no substantial direct effect (0.026, $p > .05$), yet demonstrated a significant full mediation effect (0.21, $p = 0$) of cognitive strategies on the association with HOTS, supporting hypothesis H_{2c}. The functional design displayed no significant direct effect (0.02, $p > .05$) or mediating effect (0.06, $p > .05$) on HOTS, thus not supporting hypothesis H_2d. Connectedness showed no significant direct effect (0.03, $p > .05$) or mediating effect (0.03, $p > .05$) on HOTS, leading to the lack of support for hypothesis H2e. Ease of use exhibited no significant direct effect (0.04, $p > .05$) or mediating effect (0.13, $p > .05$) on HOTS, thus not supporting hypothesis H_{2f}. Perceived usefulness displayed no significant direct effect (0.05, $p > .05$) but had a significant full mediation effect (0.24, $p < .01$) of cognitive strategies on the relationship with HOTS, confirming hypothesis H_{2g}. Multiple sources had no significant direct effect (0.03, $p > .05$) or mediating effect (0.02, $p > .05$) on HOTS, resulting in the lack of support for hypothesis H_{2h}.

In conclusion, among the eight research hypotheses (H_{2a}, H_{2b}, H_{2c}, H_{2d}, H_{2e}, H_{2f}, H_{2g}, H_{2h}), only H_{2b}, H_{2c}, and H_{2g} are supported. This indicates that cognitive strategies significantly mediate the relationships between the sub-constructs of CSLEs (inquiry learning, reflective thinking, and perceived usefulness) and HOTS. o achieve model parsimony and focus on substantively meaningful pathways, the structural model was refined (Figure 2, Table 4). The five non-significant sub-constructs were removed based on both empirical redundancy (negligible path coefficients and non-significant bootstrap intervals) and theoretical alignment with Constructivist Learning Theory, which suggests that only learning environment features directly triggering self-regulated cognitive processing exert salient indirect effects on HOTS.

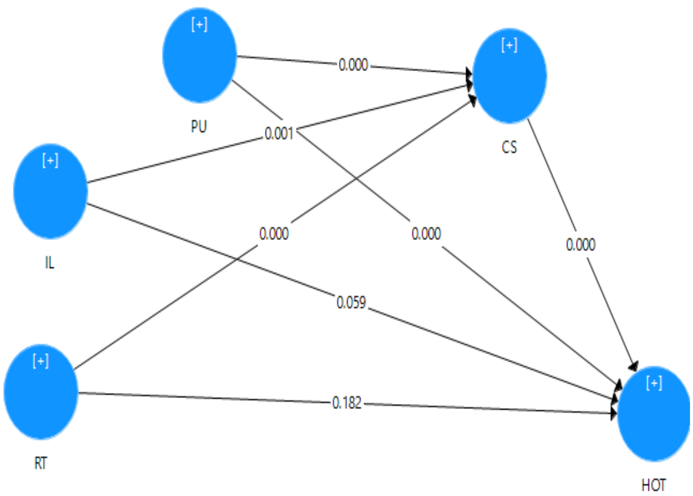

Figure 2. Revised Mediation Model.

Table 4. The mediating effects of CS on the relationships between IL, RT, PU, and HOT.

Path	Path coefficient	*t*	*p*	2.50%	97.50 %	Effect percentage（%）
IL →HOTS	0.059	1.891	0.069	0.002	0.12	30.4
RT → HOTS	0.042	1.335	0.182	-0.021	0.109	16.5
P U→HOTS	0.105	5.082	0	0.067	0.146	30.3
CS → HOTS	0.823	43.473	0	0.783	0.857	
IL →CS → HOTS	0.135	2.456	0.004	0.03	0.249	69.6
RT → CS → HOTS	0.214	4.154	0	0.107	0.309	83.5
PU → CS → HOTS	0.242	3.391	0.001	0.094	0.376	69.7

Note: High Order Thinking Skills = HOTS, Cognitive strategies = CS, Multiple sources = MS, Perceived usefulness = PU, Ease of use = EU, Connectedness = CN, Functional design = FD, Reflective thinking = RT, Inquiry-based learning = IL, Student negotiation = SN.

As shown in Table 4, the direct effect of inquiry learning on HOTS was not statistically significant (β=0.06, p>.05), whereas its indirect effect through cognitive strategies was significant (β=0.14, p<.01), indicating full mediation (accounting for 69.9% of the total effect). Similarly, reflective thinking showed a non-significant direct effect on HOTS (β=0.042, p>.05) but a significant indirect effect through cognitive strategies (β=0.21,

$p<.001$), demonstrating full mediation (83.5% of the total effect). In contrast, perceived usefulness exhibited both a significant direct effect ($\beta=0.19$, $p<.001$; 30.3% of the total effect) and a significant indirect effect through cognitive strategies ($\beta=0.24$, $p<.01$; 69.7% of the total effect), indicating complementary partial mediation**.**

5. Discussion

The primary objective of this study was to examine how specific dimensions of a CSLE influence HOTS among female pre-service teachers in China, with particular attention to the mediating mechanism of cognitive strategies. Our refined structural model demonstrated that cognitive strategies fully mediate the effects of inquiry learning and reflective thinking on HOTS, whereas perceived usefulness exerts both a significant direct effect and an indirect effect via cognitive strategies (partial mediation). Interpreted through Gibson's (1977) Affordance Theory, these findings demonstrate that technological and pedagogical features of smart learning environments function as potential action possibilities (affordances); however, their transformative impact on higher-order cognition is realized primarily when learners actively enact self-regulated cognitive strategies to exploit those affordances.

The structural model revealed that inquiry learning did not have a significant direct impact on HOTS ($\beta=0.06$, $p>.05$), but exerted a strong, positive indirect effect through cognitive strategies ($\beta=0.14$, $p<.01$). This full mediation demonstrates that exposure to inquiry-oriented smart environments alone does not automatically elevate pre-service teachers' critical thinking, analytical reasoning, or creative problem-solving. Rather, inquiry environments foster HOTS precisely because they compel students to deploy deep cognitive processing strategies across distinct phases of investigation.

This finding extends previous empirical work (Aidoo et al., 2022; Pedaste et al., 2015) by clarifying the underlying cognitive pathway. During the initial problem-definition phase, pre-service teachers formulate investigative questions and establish structured inquiry trajectories, which necessitates planning strategies. As learners proceed to the investigation phase—gathering, cross-examining, and synthesizing multi-modal digital resources—they engage elaboration strategies by connecting novel data with their prior pedagogical knowledge. When testing hypotheses and interpreting findings, students employ monitoring and regulation strategies to evaluate evidence and refine flawed assumptions. Finally, during the synthesis and presentation phase, organizational strategies (such as conceptual mapping and data structuring) enable students to translate disparate empirical observations into coherent pedagogical arguments. Thus, the affordances of inquiry-based smart environments provide the structural scaffold, but the activation of cognitive strategies serves as the psychological engine converting investigative activity into advanced thinking capabilities.

Similarly, reflective thinking exhibited a non-significant direct path to HOTS ($\beta=0.042$, $p>.05$) alongside a substantial indirect effect through cognitive strategies ($\beta=0.21$, $p<.001$), confirming full mediation. While reflective practices have long been regarded as essential in teacher education (Dewey, 1933; Gambo & Shakir, 2021), our results demonstrate that reflective prompts within CSLEs do not directly enhance higher-order cognition unless they stimulate systematic cognitive monitoring and strategic restructuring.

In CSLEs, reflection operates across three integrated temporal phases: before, during, and after instructional tasks (Avcı & Ergün, 2022). Prior to engaging in learning tasks, pre-service teachers reflect on task demands by utilizing rehearsal and planning strategies to retrieve foundational knowledge and establish benchmarks. During task execution, continuous introspection prompts real-time monitoring strategies, enabling learners to detect discrepancies, diagnose cognitive deadlocks, and calibrate their problem-solving approaches (Setiyani et al., 2024). Following task completion, post-activity reflection stimulates organizational and elaboration strategies, whereby learners evaluate outcomes, critically appraise their own pedagogical decisions, and integrate insights into long-term cognitive schemata (Lohbeck & Moschner, 2022); by clarifying the underlying cognitive pathway. During the initial problem-definition phase, pre-service teachers formulate investigative questions and establish structured inquiry trajectories, which necessitates planning strategies. As learners proceed to the investigation phase—gathering, cross-examining, and synthesizing multi-modal digital resources—they engage elaboration strategies by connecting novel data with their prior pedagogical knowledge. When testing hypotheses and interpreting findings, students employ monitoring and regulation strategies to evaluate evidence and refine flawed assumptions. Finally, during the synthesis and presentation phase, organizational strategies (such as conceptual mapping and data structuring) enable students to translate disparate empirical observations into coherent pedagogical arguments. Thus, the affordances of inquiry-based smart environments provide the structural scaffold, but the activation of cognitive strategies serves as the psychological engine converting investigative activity into advanced thinking capabilities.

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In CSLEs, reflection operates across three integrated temporal phases: before, during, and after instructional tasks (Coulson & Harvey, 2013). Prior to engaging in learning tasks, pre-service teachers reflect on task demands by utilizing rehearsal and planning strategies to retrieve foundational knowledge and establish benchmarks. During task execution, continuous introspection prompts real-time monitoring strategies, enabling learners to detect discrepancies, diagnose cognitive deadlocks, and calibrate their problem-solving approaches (Azevedo, 2026). Following task completion, post-activity reflection stimulates organizational and elaboration strategies, whereby learners evaluate outcomes, critically appraise their own pedagogical decisions, and integrate insights into long-term cognitive schemata (Beard, 2026) and integrated all sub-headings smoothly into continuous academic prose.

6. Conclusion

This study investigated the influence of CSLE components on HOTS, mediated by cognitive strategies. Findings indicate that inquiry learning**,** reflective thinking, and perceived usefulness significantly predict HOTS, primarily through the full mediation of cognitive strategies. Student negotiation did not demonstrate a significant relationship with HOTS in our model. These results highlight the critical role of actively engaging cognitive processes in leveraging CSLE affordances for HOTS development. Limitations include the specific sample and CSLE context, suggesting future research should explore diverse settings and other potential mediators. Practical implications emphasize designing CSLEs that explicitly foster strategic cognitive engagement to enhance students' critical thinking abilities.

7. Limitations of the Study

This study has several limitations. First, its cross-sectional design precludes definitive causal inferences; therefore, our reported mediation findings must be interpreted strictly as statistical associations rather than evidence of causal pathways. Second, reliance on self-reported questionnaires introduces potential common method and social desirability bias, which may inflate observed relationships. Third, generalizability is constrained by the sample, which focused exclusively on female pre-service teachers in Shanxi, China; findings may not generalize to male educators or other cultural contexts. Finally, measuring the learning environment through perceived affordances rather than direct observation means that variations in actual pedagogical implementation remain unaccounted for. Future research should utilize longitudinal, mixed-methods, or observational designs across more diverse populations to address these limitations and further validate the dynamic interactions within CSLEs.

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