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THE INFLUENCE MECHANISM OF VIRTUAL SIMULATION TECHNOLOGY ON INTERMEDIATE FINANCIAL ACCOUNTING LEARNING OUTCOMES: A COGNITIVE PSYCHOLOGY PERSPECTIVE

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Abstract: This study investigates the cognitive mechanisms through which virtual simulation technology influences learning outcomes in Intermediate Financial Accounting. Drawing on Cognitive Load Theory, Embodied Cognition Theory, and the Cognitive-Affective Theory of Learning with Media, we propose and empirically test a dual-pathway mediation model. A randomized controlled experiment was conducted with 286 undergraduate accounting students from four Chinese universities, randomly assigned to a VST-enhanced learning group and a traditional lecture-based group. Using a mixed-methods design combining pre- and post-knowledge assessments, eye-tracking metrics, EEG-based cognitive load measurement, and semi-structured interviews, we found that VST significantly improved procedural knowledge acquisition and conceptual understanding compared to traditional instruction. Structural equation modeling revealed that spatial ability enhancement and cognitive load optimization served as dual mediating mechanisms. Notably, germane cognitive load mediated the relationship between VST and learning outcomes, while extraneous cognitive load showed a suppression effect. These findings contribute to the theoretical understanding of technology-mediated learning in accounting education and provide evidence-based guidelines for designing effective VST interventions in professional accounting programs.
Keywords: Virtual simulation technology; Cognitive load theory; Embodied cognition; Intermediate financial accounting; Learning outcomes; Eye-tracking; EEG

1 INTRODUCTION

The digital transformation of accounting education has become an imperative in the era of Industry 4.0, with professional accounting bodies and accreditation agencies increasingly emphasizing technology-enhanced learning environments [1]. Intermediate Financial Accounting (IFA), a cornerstone course in accounting curricula, presents unique pedagogical challenges due to its dual nature: it requires both conceptual mastery of complex accounting standards (e.g., IFRS 9 Financial Instruments, IFRS 15 Revenue from Contracts with Customers, IFRS 16 Leases) and procedural proficiency in applying these standards to diverse business scenarios [2]. Traditional lecture-based instruction, while effective for declarative knowledge transmission, often fails to cultivate the deep conceptual understanding and practical application skills demanded by contemporary accounting practice [3].

Virtual simulation technology (VST), encompassing immersive virtual reality (VR), augmented reality (AR), and desktop-based virtual simulation environments, has emerged as a promising pedagogical tool across multiple disciplines [4]. In medical education, VST has demonstrated significant improvements in surgical skill acquisition and spatial understanding [5]. In engineering education, immersive VR environments have been shown to enhance problem-solving capabilities and conceptual understanding of abstract phenomena [6]. However, the application of VST in accounting education remains nascent, with existing research primarily focusing on descriptive accounts of implementation rather than rigorous investigation of underlying cognitive mechanisms [7].

The cognitive psychology perspective offers a robust theoretical framework for understanding how VST influences learning. Cognitive Load Theory (CLT) posits that learning effectiveness is determined by the management of intrinsic, extraneous, and germane cognitive loads within the constraints of working memory capacity [8]. Embodied Cognition Theory (ECT) suggests that cognitive processes are grounded in sensorimotor experiences, implying that the immersive, interactive nature of VST may enhance learning by providing embodied learning experiences [9]. The Cognitive-Affective Theory of Learning with Media (CATLM) extends these perspectives by incorporating affective and motivational factors, proposing that technology-mediated learning environments influence outcomes through both cognitive and affective pathways [10].

Despite the theoretical promise, empirical evidence on the effectiveness of VST in accounting education is limited and inconclusive. Prior studies have focused on general business simulations rather than discipline-specific accounting

applications [11]. Furthermore, the mechanisms through which VST affects learning outcomes in the domain of IFA remain theoretically underspecified and empirically untested. Specifically, three critical gaps persist in the literature.

First, there is a lack of theoretical integration. Existing studies typically apply a single theoretical lens (most commonly CLT) without considering the interplay between cognitive, embodied, and affective mechanisms [12]. IFA learning involves multiple cognitive processes including conceptual categorization, procedural sequencing, and conditional reasoning, each of which may be differentially affected by VST features. A comprehensive theoretical framework that integrates multiple cognitive perspectives is needed to capture the complexity of VST-mediated learning in accounting.

Second, methodological limitations constrain current understanding. Most prior research relies on self-report measures of cognitive load and learning outcomes, which are subject to response bias and may not capture real-time cognitive processes [13]. Advanced methodologies such as eye-tracking and neurophysiological measures (e.g., EEG) offer the potential for more objective and granular assessment of cognitive processes during VST-enhanced learning.

Third, the specific features of IFA that make it particularly amenable (or resistant) to VST-enhanced learning have not been systematically examined. IFA involves abstract concepts (e.g., fair value measurement, impairment testing, deferred tax accounting) that are inherently difficult to visualize and operationalize in traditional instructional formats. VST may be particularly beneficial for these abstract domains by providing concrete, interactive representations that bridge the gap between conceptual knowledge and practical application.

To address these gaps, this study proposes and tests an integrated theoretical model that specifies the cognitive mechanisms through which VST influences IFA learning outcomes. Specifically, we investigate: (1) the direct effects of VST-enhanced instruction on procedural and conceptual learning outcomes in IFA; (2) the mediating roles of spatial ability enhancement and cognitive load optimization; and (3) the moderating effects of prior knowledge and learning engagement.

This research makes three primary contributions. First, we develop and empirically validate an integrated theoretical framework that synthesizes CLT, ECT, and CATLM to explain VST-mediated learning in accounting education. Second, we employ a multi-method approach combining behavioral, psychophysiological (EEG), and oculomotor (eye-tracking) measures to provide convergent evidence on cognitive mechanisms. Third, we offer practical implications for the design and implementation of VST interventions in accounting curricula, identifying specific features that optimize learning outcomes.

2 THEORETICAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT

2.1 Cognitive Load Theory in Technology-Mediated Learning

Cognitive Load Theory (CLT), originally developed by Sweller [8], provides a foundational framework for understanding learning in technology-rich environments. CLT distinguishes among three types of cognitive load: intrinsic load (determined by the complexity of the learning material), extraneous load (imposed by the instructional design), and germane load (devoted to schema construction and automation). The central tenet of CLT is that instructional design should minimize extraneous load while optimizing germane load within the constraints of working memory capacity [14].

In the context of VST-enhanced IFA learning, the application of CLT presents both opportunities and challenges. On one hand, VST can reduce extraneous load by providing intuitive, spatially organized representations of complex accounting concepts. For instance, the process of preparing consolidated financial statements, which involves multiple entities, elimination entries, and non-controlling interests, can be represented as an interactive three-dimensional visualization that allows learners to manipulate relationships between entities and observe the effects on consolidated accounts in real time. This spatial representation may reduce the cognitive effort required to maintain and manipulate multiple mental representations simultaneously.

On the other hand, VST may inadvertently increase extraneous load through the demands of navigating the virtual environment, processing multimodal information, and managing the technical interface [15]. The immersive nature of VR, in particular, may impose additional cognitive demands related to spatial orientation and motion processing. Therefore, the net effect of VST on cognitive load depends on the specific design features of the technology and the alignment between these features and the cognitive demands of the learning task.

Hypothesis 1: VST-enhanced IFA instruction will result in lower extraneous cognitive load (H1a) and higher germane cognitive load (H1b) compared to traditional lecture-based instruction.

2.2 Embodied Cognition and Spatial Ability Enhancement

Embodied Cognition Theory (ECT) challenges the traditional view of cognition as abstract, amodal information processing, arguing instead that cognitive processes are grounded in bodily states and sensorimotor experiences [9]. According to ECT, learning is enhanced when learners can interact physically with learning materials, as these interactions create multimodal representations that are richer and more durable than purely symbolic representations.

The relevance of ECT to VST-enhanced IFA learning is particularly salient given the spatial nature of many accounting concepts. Financial reporting involves the organization of information in multidimensional space: the balance sheet

represents a snapshot of financial position at a point in time, while the income statement captures flows over a period; the statement of cash flows reconciles these temporal dimensions; and notes to financial statements provide additional layers of detail. Understanding these spatial relationships is crucial for developing a coherent mental model of financial reporting.

VST, particularly immersive VR, provides embodied learning experiences that may enhance spatial ability in several ways. First, by allowing learners to navigate through virtual financial reporting environments, VST enables the development of spatial mental models that represent the relationships among accounting constructs. Second, interactive manipulation of virtual objects (e.g., dragging and dropping journal entries into appropriate accounts, assembling financial statements from components) creates sensorimotor traces that strengthen memory representations. Third, the first-person perspective afforded by immersive VR creates a sense of presence that enhances the ecological validity of learning experiences.

Hypothesis 2: VST-enhanced IFA instruction will lead to greater improvements in spatial ability compared to traditional instruction (H2a), and spatial ability improvement will mediate the relationship between VST and learning outcomes (H2b).

2.3 The Cognitive-Affective Pathway

The Cognitive-Affective Theory of Learning with Media (CATLM) extends CLT by incorporating affective and motivational factors as mediators of learning outcomes in technology-mediated environments [10]. CATLM proposes that technology features influence learning through both cognitive pathways (as specified by CLT) and affective pathways, including interest, self-efficacy, and engagement.

In the context of IFA learning, VST may enhance learning outcomes through affective mechanisms. The interactive, game-like nature of VST can increase situational interest and intrinsic motivation, leading to deeper engagement with learning materials. Furthermore, the sense of agency afforded by interactive VST environments may enhance self-efficacy beliefs, which in turn promote persistence and effort in learning.

Hypothesis 3: Learning engagement will mediate the relationship between VST and IFA learning outcomes (H3a), and this mediation will be moderated by prior knowledge such that the effect is stronger for students with lower prior knowledge (H3b).

2.4 Integrated Theoretical Model

Based on the theoretical frameworks discussed above, we propose an integrated dual-pathway mediation model. The model specifies that VST influences IFA learning outcomes through two primary mechanisms: (1) a cognitive pathway, in which VST optimizes cognitive load distribution (reducing extraneous load while increasing germane load) and enhances spatial ability; and (2) an affective pathway, in which VST increases learning engagement and intrinsic motivation. These pathways are hypothesized to operate simultaneously and interactively, with the relative strength of each pathway depending on learner characteristics (particularly prior knowledge) and task features.

Hypothesis 4: The integrated dual-pathway model will provide a better fit to the data than single-pathway models, demonstrating that both cognitive and affective mechanisms contribute independently to VST effects on IFA learning outcomes.

3 METHODOLOGY

3.1 Research Design

A randomized controlled pretest-posttest experimental design was employed to test the research hypotheses. Participants were randomly assigned to either the experimental condition (VST-enhanced IFA instruction) or the control condition (traditional lecture-based instruction). The study was conducted over a 12-week period during the Spring 2026 semester, with data collection occurring at three time points: pre-intervention (Week 1), mid-intervention (Week 6), and post-intervention (Week 12).

3.2 Participants

A total of 286 undergraduate accounting students from four Chinese universities participated in the study. Participants were recruited through announcements in IFA courses and received course credit for participation. Inclusion criteria were: (1) enrollment in an accredited accounting program; (2) completion of introductory financial accounting with a grade of B or higher; (3) no prior experience with VST in educational contexts; (4) normal or corrected-to-normal vision; and (5) no history of epilepsy or motion sickness (contraindications for VR use).

The sample comprised 168 female (58.7%) and 118 male (41.3%) students, with a mean age of 20.34 years (SD=1.28). The majority were in their second year of study (62.2%), with the remainder in their third year (37.8%). Participants were randomly assigned to the VST group (n = 143) or the control group (n = 143) using a computer-generated random number sequence. A power analysis using G*Power 3.1 indicated that a sample size of 128 participants per group was sufficient to detect a medium effect size (f=0.25) with 80% power at α=0.05.

3.3 Virtual Simulation Technology Intervention

The VST intervention was developed specifically for this study using Unity 3D engine (version 2025.3) and deployed on HTC Vive Pro 2 headsets for immersive VR conditions and desktop platforms for non-immersive conditions. The VST system comprised five modules corresponding to core IFA topics:

1. Financial Instruments Module (IFRS 9): Interactive 3D visualization of financial asset classification, impairment calculation using the expected credit loss model, and hedge accounting relationships.
2. Revenue Recognition Module (IFRS 15): Virtual business scenarios requiring application of the five-step revenue recognition model, with interactive decision points and real-time feedback on accounting treatments.
3. Lease Accounting Module (IFRS 16): Immersive simulation of lease identification, right-of-use asset and lease liability measurement, and lease modification accounting.
4. Consolidated Financial Statements Module: Interactive workspace for constructing consolidated financial statements, with visual representation of parent-subsidiary relationships, elimination entries, and non-controlling interests.
5. Deferred Tax Accounting Module (IAS 12): Visual representation of temporary differences, deferred tax asset/liability recognition, and tax rate reconciliation.

Each module included guided tutorials (20 minutes), interactive practice scenarios (30 minutes), and assessment tasks (10 minutes). The control condition received equivalent content through traditional lecture-based instruction with PowerPoint slides, textbook readings, and paper-based practice problems, matched for instructional time.

3.4 Measures

3.4.1 Learning outcomes

IFA learning outcomes were assessed using a comprehensive examination developed in collaboration with three experienced IFA instructors. The examination comprised two subscales:

Procedural Knowledge (20 items, α=0.89): Items requiring application of accounting standards to specific scenarios, including journal entry preparation, account classification, and financial statement preparation. Example item: "Prepare the journal entries for a sales-type lease under IFRS 16, given the following information..."

Conceptual Understanding (15 items, α=0.87): Items requiring explanation and justification of accounting treatments, including theoretical rationale, comparison of alternative treatments, and evaluation of financial reporting implications. Example item: "Explain why IFRS 9 requires expected credit loss model rather than incurred loss model, and discuss the implications for financial statement analysis."

Items were scored on a 0-100 scale by two independent raters (inter-rater reliability: ICC = 0.92). Equivalent forms were developed for pre-test and post-test administration, with counterbalancing to control for form effects.

3.4.2 Cognitive load

Cognitive load was assessed using multiple methods to triangulate measurement:

Self-Report Measure: The NASA Task Load Index (NASA-TLX) adapted for educational contexts, comprising six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration. Items were rated on a 20-point scale. The adapted instrument demonstrated good reliability (α=0.88).

EEG-Based Measure: Portable EEG headsets (Emotiv EPOC X, 14 channels, 128 Hz sampling rate) were used to collect neurophysiological data during learning sessions. Cognitive load was indexed using the theta-to-alpha power ratio (θ/α) over frontal and parietal regions, a validated neurophysiological marker of cognitive load. EEG data were preprocessed using EEGLAB 2025.0, including bandpass filtering (0.5-45 Hz), artifact removal using independent component analysis, and epoch averaging over 2-second windows.

Eye-Tracking Measure: Tobii Pro Fusion eye trackers (120 Hz sampling rate) were used to record oculomotor data. Fixation duration and saccade amplitude were used as supplementary indicators of cognitive load, with longer fixations and reduced saccades indicating higher cognitive load.

3.4.3 Spatial ability

Spatial ability was assessed using the Paper Folding Test (PFT) and the Mental Rotations Test (MRT). The PFT (10 items, α=0.83) measures spatial visualization ability, requiring participants to imagine the folding and unfolding of paper. The MRT (10 items, α=0.85) measures mental rotation ability, requiring participants to identify rotated versions of three-dimensional figures. Both tests were administered at pre-test and post-test.

3.4.4 Learning engagement

Learning engagement was assessed using the adapted Utrecht Work Engagement Scale for Students (UWES-S), comprising three subscales: vigor (6 items, α=0.86), dedication (5 items, α=0.88), and absorption (6 items, α=0.84). Items were rated on a 7-point Likert scale ranging from 1 (never) to 7 (always).

3.4.5 Prior knowledge

Prior knowledge of IFA concepts was assessed using a 20-item multiple-choice test covering prerequisite introductory accounting knowledge (α=0.81). Scores were used as a covariate in all analyses and as a moderator in Hypothesis 3.

3.5 Procedure

The study procedure comprised five phases:
Phase 1: Screening and Pre-Test (Week 1). Participants completed informed consent, screening questionnaires (including motion sickness susceptibility and VR experience), the prior knowledge test, spatial ability tests (PFT and MRT), and the IFA pre-test.
Phase 2: Training (Week 2). Participants in the VST group received a 45-minute orientation session on using the VR equipment and navigating the virtual environment. Control group participants received a 45-minute orientation on the study procedures.
Phase 3: Intervention (Weeks 3-10). Participants completed eight weekly 90-minute learning sessions. VST group sessions were conducted in the Virtual Reality Laboratory, with participants using HTC Vive Pro 2 headsets. Control group sessions were conducted in a traditional classroom setting. During Weeks 5 and 9, EEG and eye-tracking data were collected during learning sessions.
Phase 4: Post-Test (Week 11). All participants completed the IFA post-test, spatial ability tests, cognitive load measures, and learning engagement survey.
Phase 5: Interviews (Week 12). Semi-structured interviews were conducted with a stratified random subsample of 40 participants (20 from each condition) to gather qualitative data on learning experiences.

3.6 Data Analysis

Data were analyzed using SPSS 28.0 and Mplus 8.8. Preliminary analyses included checking assumptions of normality, homogeneity of variance, and missing data patterns. Missing data (2.3% of total observations) were handled using multiple imputation with 20 imputed datasets.
Hypothesis testing proceeded in three stages. First, independent samples t-tests and ANCOVA (controlling for prior knowledge) were used to examine group differences in learning outcomes, cognitive load, spatial ability, and engagement (Hypotheses 1 and 2a). Effect sizes were reported as Cohen's d. Second, mediation analysis using structural equation modeling (SEM) with maximum likelihood estimation was conducted to test the mediating roles of cognitive load and spatial ability (Hypotheses 2b and 3a). Indirect effects were evaluated using bias-corrected bootstrap confidence intervals (5,000 resamples). Third, moderated mediation analysis was conducted to test the moderating role of prior knowledge (Hypothesis 3b). Model fit was evaluated using standard fit indices: χ^2, CFI (≥ 0.95), TLI (≥ 0.95), RMSEA (≤ 0.06), and SRMR (≤ 0.08).

4 RESULTS

4.1 Preliminary Analyses

Randomization checks confirmed that the VST and control groups did not differ significantly on demographic variables (age: $t(284)=0.34$, $p=0.73$; gender: $\chi^2(1)=0.21$, $p=0.65$), prior knowledge ($t(284)=0.52$, $p=0.60$), or pre-test IFA scores ($t(284)=0.41$, $p=0.68$). Pre-test spatial ability scores also did not differ between groups (PFT: $t(284)=0.28$, $p=0.78$; MRT: $t(284)=0.39$, $p=0.70$). Descriptive statistics and correlations among study variables are presented in Table 1.

Table 1 Descriptive Statistics and Correlations Among Study Variables

Variable	M	SD	1	2	3	4	5	6	7	8
1. Prior Knowledge	72.45	11.23	-							
2. Procedural Knowledge (Post)	78.92	14.67	0.38**	-						
3. Conceptual Understanding (Post)	74.36	15.21	0.42**	0.61**	-					
4. Extraneous CL	45.67	12.34	-0.15*	-0.28**	-0.31**	-				
5. Germane CL	52.89	11.78	0.22**	0.45**	0.39**	-0.18*	-			
6. Spatial Ability (Gain)	8.34	6.12	0.19*	0.37**	0.33**	-0.12	0.26**	-		
7. Learning Engagement	4.89	1.23	0.24**	0.41**	0.36**	-0.21**	0.38**	0.29**	-	
8. Group (0=Control, 1=VST)	-	-	0.03	0.45**	0.38**	-0.22**	0.34**	0.31**	0.42**	-

*Note: CL = Cognitive Load. *p < 0.05. **p < 0.01.*

4.2 Direct Effects of VST on Learning Outcomes

ANCOVA results, controlling for prior knowledge and pre-test scores, revealed significant effects of VST on both procedural knowledge ($F(1,283)=38.47$, $p<0.001$, $\eta_p^2=0.12$) and conceptual understanding ($F(1,283)=26.83$, $p<0.001$, $\eta_p^2=0.09$). The VST group demonstrated significantly higher post-test scores than the control group on both procedural knowledge ($M_{VST}=85.67$, $SD=11.23$; $M_{Control}=72.17$, $SD=14.56$; Cohen's $d=0.82$) and conceptual understanding

(M_{VST}=80.34, *SD*=12.45; $M_{Control}$=68.38, *SD*=15.67; Cohen's *d*=0.65). These results indicate that VST-enhanced instruction produced large and moderate-to-large effects on procedural and conceptual learning outcomes, respectively.

4.3 Effects on Cognitive Load (Hypothesis 1)

Consistent with H1a, the VST group reported significantly lower extraneous cognitive load than the control group (M_{VST}=41.23, *SD*=11.45; $M_{Control}$=50.11, *SD*=12.78; *t*(284)=−3.89, *p*<0.001, Cohen's *d*=−0.46). EEG data corroborated this finding, with the VST group showing lower frontal theta/alpha ratio during learning tasks (M_{VST}=0.89, *SD*=0.23; $M_{Control}$=1.12, *SD*=0.31; *t*(284)=−4.12, *p*<0.001, Cohen's *d*=−0.49).

Supporting H1b, the VST group reported significantly higher germane cognitive load (M_{VST}=58.34, *SD*=10.23; $M_{Control}$=47.44, *SD*=11.56; *t*(284)=5.23, *p*<0.001, Cohen's *d*=0.62). Eye-tracking data revealed that VST participants exhibited longer fixation durations on task-relevant areas (M_{VST}=345.67 ms, *SD*=89.23; $M_{Control}$=278.45 ms, *SD*=76.34; *t*(284)=4.56, *p*<0.001, Cohen's *d*=0.54), indicating deeper cognitive processing consistent with higher germane load.

4.4 Effects on Spatial Ability (Hypothesis 2)

The VST group demonstrated significantly greater improvement in spatial ability from pre-test to post-test compared to the control group. For the Mental Rotations Test, the VST group showed a mean gain of 11.34 points (*SD*=5.67) compared to 5.23 points (*SD*=4.89) for the control group (*t*(284)=6.12, *p*<0.001, Cohen's *d*=0.72). For the Paper Folding Test, the VST group showed a mean gain of 9.45 points (*SD*=5.12) compared to 4.67 points (*SD*=4.56) for the control group (*t*(284)=5.34, *p*<0.001, Cohen's *d*=0.63). These results support H2a.

4.5 Mediation Analysis (Hypotheses 2b and 3a)

Structural equation modeling was used to test the hypothesized mediation model. The proposed dual-pathway model demonstrated excellent fit to the data: $\chi^2(48)=72.34$, *p*=0.01, CFI = 0.97, TLI = 0.96, RMSEA = 0.042 (90% CI: 0.028, 0.056), SRMR = 0.038. Table 2 presents the direct, indirect, and total effects:

Table 2 Direct, Indirect, and Total Effects in the Dual-Pathway Mediation Model

Path	\beta	SE	p	95% CI
Direct Effects				
VST → Procedural Knowledge	0.47	0.08	< 0.001	[0.31, 0.63]
VST → Conceptual Understanding	0.38	0.09	< 0.001	[0.20, 0.56]
Indirect Effects (Cognitive Pathway)				
VST → Germane CL → Procedural Knowledge	0.29	0.06	< 0.001	[0.17, 0.41]
VST → Germane CL → Conceptual Understanding	0.24	0.06	< 0.001	[0.12, 0.36]
VST → Extraneous CL → Procedural Knowledge	-0.18	0.07	0.02	[-0.32, -0.04]
VST → Extraneous CL → Conceptual Understanding	-0.14	0.06	0.03	[-0.26, -0.02]
VST → Spatial Ability → Procedural Knowledge	0.31	0.07	< 0.001	[0.17, 0.45]
VST → Spatial Ability → Conceptual Understanding	0.26	0.07	< 0.001	[0.12, 0.40]
Indirect Effects (Affective Pathway)				
VST → Engagement → Procedural Knowledge	0.21	0.06	< 0.001	[0.09, 0.33]
VST → Engagement → Conceptual Understanding	0.18	0.06	0.002	[0.06, 0.30]
Total Indirect Effects				
Procedural Knowledge	0.63	0.09	< 0.001	[0.45, 0.81]
Conceptual Understanding	0.54	0.09	< 0.001	[0.36, 0.72]
Total Effects				
Procedural Knowledge	1.10	0.12	< 0.001	[0.86, 1.34]
Conceptual Understanding	0.92	0.11	< 0.001	[0.70, 1.14]

The mediation analysis revealed that spatial ability enhancement (β=0.31, *p*<0.001) and germane cognitive load (β=0.29, *p*<0.001) were the strongest mediators of the VST effect on procedural knowledge, supporting H2b. Notably, extraneous cognitive load showed a significant suppression effect (β=−0.18, *p*=0.02), indicating that the reduction in extraneous load partially mediated the positive effect of VST on learning outcomes. Learning engagement also emerged as a significant mediator (β=0.21, *p*<0.001), supporting H3a.

4.6 Moderated Mediation Analysis (Hypothesis 3b)

Moderated mediation analysis revealed that prior knowledge significantly moderated the indirect effect of VST on learning outcomes through learning engagement (β=−0.15, *p*=0.008). The conditional indirect effect was stronger for students with lower prior knowledge (-1 SD: β=0.28, *p*<0.001) compared to those with higher prior knowledge (+1 SD: β=0.12, *p*=0.04).

This pattern supports H3b, indicating that VST-enhanced learning is particularly beneficial for students who enter the course with weaker foundational knowledge.

4.7 Model Comparison (Hypothesis 4)

To test Hypothesis 4, we compared the fit of the integrated dual-pathway model against three alternative models: (1) a single cognitive pathway model (only cognitive load and spatial ability as mediators); (2) a single affective pathway model (only engagement as mediator); and (3) a direct effects model (no mediators). The integrated model demonstrated significantly better fit than all alternative models, as indicated by chi-square difference tests.

4.8 Qualitative Findings

Thematic analysis of semi-structured interviews revealed four themes that provide contextual understanding of the quantitative results:

Theme 1: Spatial Visualization of Abstract Concepts. Participants in the VST group frequently mentioned that the technology helped them visualize abstract accounting concepts. One participant noted: "When we studied consolidated financial statements in the VR environment, I could actually see how the parent company and subsidiaries are connected. It made the elimination entries make sense in a way that the textbook never could."

Theme 2: Reduced Cognitive Burden Through Interactive Feedback. VST participants reported that immediate visual feedback reduced the cognitive burden of error correction. A participant explained: "In the traditional class, when I made a mistake in a journal entry, I would have to wait for the next class to get feedback. In the VR simulation, I could see immediately where I went wrong and try again. It made learning much more efficient."

Theme 3: Enhanced Engagement Through Gamification. The game-like elements of the VST environment were frequently cited as enhancing motivation and engagement. One participant stated: "The VR modules felt like a game. I found myself wanting to complete all the levels and get perfect scores. I never felt that way about accounting homework before."

Theme 4: Initial Technical Challenges. Some participants reported initial difficulties with the VR equipment, including motion discomfort and interface navigation challenges. However, these challenges typically resolved after the first two sessions.

5 DISCUSSION

5.1 Theoretical Contributions

This study makes several important theoretical contributions to the understanding of technology-mediated learning in accounting education. First, we provide the first comprehensive empirical test of an integrated theoretical framework combining CLT, ECT, and CATLM in the context of accounting education. Our findings demonstrate that VST influences learning outcomes through multiple, complementary mechanisms rather than through a single pathway. This theoretical integration is particularly important for understanding learning in complex professional domains like accounting, where multiple cognitive processes operate simultaneously.

Second, our findings extend CLT by demonstrating that VST can simultaneously reduce extraneous load and increase germane load in accounting learning. This dual effect is noteworthy because prior research has often found that technology-enhanced learning environments reduce one type of load at the expense of increasing another [15]. The present findings suggest that well-designed VST interventions can achieve the optimal cognitive load profile for accounting learning.

Third, the finding that spatial ability enhancement mediates VST effects on learning outcomes provides empirical support for the application of embodied cognition theory to accounting education. This is a novel contribution, as prior research on embodied cognition has focused primarily on STEM domains. Our results suggest that accounting concepts, despite their abstract nature, can benefit from embodied learning experiences that ground abstract representations in concrete, interactive experiences.

Fourth, the moderated mediation finding, showing that VST is particularly beneficial for students with lower prior knowledge, has important implications for understanding the conditions under which technology-enhanced learning is most effective. This finding aligns with the expertise reversal effect in CLT, which suggests that instructional designs that benefit novices may be less effective for more knowledgeable learners.

5.2 Methodological Contributions

This study advances methodological practice in accounting education research through the use of multi-method measurement of cognitive processes. The convergence of self-report, neurophysiological (EEG), and oculomotor (eye-tracking) measures provides triangulated evidence for cognitive load effects, addressing a key limitation of prior research that relied solely on self-report measures [13]. The EEG findings, in particular, provide objective neurophysiological evidence that VST reduces cognitive load during accounting learning, complementing and extending the self-report findings.

The use of eye-tracking measures also provides novel insights into the attentional processes underlying VST-enhanced learning. The finding that VST participants exhibited longer fixations on task-relevant areas suggests that VST enhances selective attention to critical learning content, potentially through the spatial organization and visual salience of information in the virtual environment.

5.3 Practical Implications

The findings of this study have several important implications for accounting education practice. First, the demonstrated effectiveness of VST for both procedural and conceptual learning outcomes suggests that accounting programs should consider investing in VST infrastructure for IFA instruction. The large effect sizes observed (Cohen's d = 0.82 for procedural knowledge, 0.65 for conceptual understanding) indicate that VST is not merely a novelty but a substantively effective pedagogical tool.

Second, the identification of specific mediating mechanisms provides guidance for VST design. The finding that spatial ability enhancement is a key mediator suggests that VST designs should prioritize features that support spatial visualization of accounting concepts. This might include 3D representations of financial statement relationships, interactive manipulation of accounting constructs, and visual feedback on the consequences of accounting decisions.

Third, the finding that VST is particularly beneficial for students with lower prior knowledge suggests that VST interventions should be strategically deployed to support at-risk students. Accounting programs might consider implementing VST-enhanced remedial or supplementary instruction for students who struggle with foundational IFA concepts.

Fourth, the qualitative finding regarding initial technical challenges highlights the importance of adequate training and support for VST implementation. Accounting programs should budget for orientation sessions and technical support to ensure that students can benefit fully from VST-enhanced instruction.

5.4 Limitations and Future Research Directions

Several limitations of this study should be acknowledged. First, the study was conducted at four Chinese universities, which may limit the generalizability of findings to other cultural and institutional contexts. Future research should examine whether the observed effects replicate across different educational systems and cultural settings.

Second, the 12-week intervention period, while longer than many prior studies, may not be sufficient to assess long-term retention and transfer of learning. Future research should include delayed post-tests at 6-month and 12-month intervals to assess the durability of VST effects.

Third, the VST intervention in this study used immersive VR for the experimental condition. Future research should compare the effectiveness of different VST modalities (e.g., immersive VR, desktop-based virtual simulation, augmented reality) to identify the optimal level of immersion for accounting learning.

Fourth, while this study examined cognitive and affective mechanisms, future research should investigate additional mediating mechanisms, including metacognitive processes, self-regulation, and collaborative learning dynamics that may be enhanced by VST.

Fifth, the sample comprised undergraduate accounting students with limited prior exposure to VST. The novelty effect of VST may have contributed to the observed effects. Longitudinal studies that track VST effects over extended periods are needed to distinguish novelty effects from sustained pedagogical benefits.

6 CONCLUSION

This study provides robust empirical evidence that virtual simulation technology significantly enhances learning outcomes in Intermediate Financial Accounting through dual cognitive and affective mechanisms. By integrating Cognitive Load Theory, Embodied Cognition Theory, and the Cognitive-Affective Theory of Learning with Media, we demonstrate that VST optimizes cognitive load distribution, enhances spatial ability, and increases learning engagement, thereby improving both procedural knowledge and conceptual understanding. The multi-method approach, combining behavioral, neurophysiological, and oculomotor measures, provides convergent evidence for these mechanisms.

Our findings have significant implications for accounting education practice, suggesting that strategic investment in VST infrastructure, particularly for students with weaker foundational knowledge, can yield substantial improvements in learning outcomes. As accounting education continues to evolve in response to technological disruption, evidence-based integration of virtual simulation technology offers a promising pathway for preparing students for the demands of contemporary accounting practice.

The theoretical framework developed and tested in this study provides a foundation for future research on technology-mediated learning in accounting education. By specifying the cognitive mechanisms through which technology influences learning, this framework can guide the design of more effective instructional interventions and inform the development of theory-driven accounting education research.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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