



Virtual-Physical Integration for Intelligent Engineering Investment Teaching in Finance and Economics Universities

Quan Mao¹

Abstract

A major challenge in engineering management education at finance and economics universities is the limited depth of students' engineering and technological foundations, even as the demand for decision-making competence in complex practical scenarios continues to grow. This condition requires a practical teaching model that can effectively connect technical understanding, decision simulation, and managerial integration. This study aims to develop and evaluate a practical teaching model for intelligent engineering investment that integrates virtual simulation and physical experimentation within the Engineering Management Program at Central University of Finance and Economics. The study employed a controlled experimental design by dividing students into three groups: a virtual simulation-based learning group, a physical experiment group, and a combined virtual-physical learning group. Evaluation was conducted using multidimensional questionnaires covering knowledge construction, skill development, cognitive experience, innovation capability, and teaching feedback. The data were analyzed using Analysis of Variance to identify differences in effectiveness among the teaching models. The findings indicate that the integrated virtual-physical model achieved superior outcomes compared with single-mode approaches across all assessed dimensions. Physical experimentation strengthened students' foundational understanding and concrete technical comprehension, whereas virtual simulation supported the exploration of complexity, dynamic scenarios, and management-based decision-making. The implications of this study suggest that the integration of physical experimentation and virtual simulation can serve as an operational paradigm for reforming engineering practice education, particularly in finance and economics institutions that require a balanced development of technological competence, investment analysis, and managerial decision-making capability in response to the demands of new infrastructure initiatives and emerging engineering education.

Keywords: *Engineering Investment, Finance and Economics Universities, Physical Experiment, Practice Teaching, Virtual Simulation.*

A. Introduction

As China advances its national strategies for "New Infrastructure, New Urbanization, and Major Projects", modern engineering endeavors are becoming increasingly complex, systematic, and intelligent. This evolution imposes new requirements on the cultivation of engineering management talent. Graduates must not only understand management and economics but also possess technical proficiency and sound decision-making acumen. However, engineering management programs in finance and economics universities, exemplified by the Central

¹School of Management Science and Engineering, Central University of Finance and Economics, Beijing, China, 100081, quanmao@cufe.edu.cn

University of Finance and Economics, face persistent structural challenges in fostering students' engineering technology literacy.

First, the lack of physical engineering laboratory facilities is a common pain point. The large-scale laboratories for material mechanics and structural engineering found in traditional engineering universities are difficult to replicate in finance and economics institutions due to significant resource investment and limited specialized faculty (Dunmoye, Moyaki, Oje, Hunsu, & May,2023). Second, pure theoretical instruction often remains disconnected from real-world engineering contexts (Walsh et al.,2018). Even when students master theories of investment analysis and project management, they frequently lack intuitive cognition and hands-on verification skills when confronted with specific technical-economic coupling problems, such as "Under what load does a concrete beam crack?" or "How does the grade of cement practically affect project cost?". Third, traditional virtual simulation experiments can suffer from being castles in the air. While virtual simulation excels at constructing complex, costly, or dangerous engineering scenarios, a lack of fundamental tactile perception of physical materials and components may lead students to perform operations that violate physical laws (Li & Liang,2024), resulting in distorted outcomes and shallow reflection (Kang, Chang, & Kim,2025).

To address these issues, the global engineering education community has explored various solutions. On one hand, physical experiments, characterized by refined operation, varied outcomes, and authentic sensory feedback, can stimulate student interest and deepen their understanding of the nature and mechanisms of engineering materials and structures. In Bhute et al. (2021)'s systematic review of the transition from traditional to remote teaching laboratories, noted that hybrid models (combining physical and virtual elements) effectively maintain learning outcomes while better adapting to diverse institutional resource constraints. On the other hand, virtual simulation breaks through limitations of time, space, and cost, recreating complex scenarios for immersive decision-making practice (Hernandez, Hernandez, Camillo, & Padilha,2025; Huang,2018; Wang, Wu, Wang, Chi, & Wang,2018). Potkonjak et al. (2016) reviewed virtual labs in science and engineering education, highlighting their unique value in allowing students to repeatedly conduct operations that are difficult or impossible to perform in real settings.

Yet, existing research often treats these two approaches as parallel or merely complementary, with limited exploration of the intrinsic logic and pedagogical mechanisms of their deep integration. In Beier & Rau's (2022) study on embodied cognition mechanisms in virtual and physical chemistry learning, they found that providing embodied experiences early in the learning sequence enhances conceptual learning. This insight offers important theoretical guidance for sequencing instruction that blends virtual and physical modes (Burleson et al.,2018; Frank & Kapila,2017). This study posits that physical experiments serve as the foundation, providing perception of engineering's micro-essence, while virtual simulation acts as the superstructure, enabling intelligent decision-making in macroscopic, complex scenarios. Virtual simulation detached from a physical foundation is rootless, while physical experiments without virtual extension struggle to address the intricacies of modern engineering. Therefore, exploring an integrated virtual-physical teaching model holds significant theoretical value and practical relevance for cultivating compound engineering investment talent equipped with both robust engineering intuition and complex systems decision-making skills.

This study utilizes core courses such as Building Architecture, Building Structures, and Comprehensive Practice in Engineering Management at the Central University of Finance and Economics. Leveraging cross-university laboratory resources shared within the Shahe Higher Education Park Alliance, this study designed and implemented a virtual-physical integration

teaching plan. Through rigorous controlled experimentation and One-way Analysis of Variance (ANOVA), this study aims to answer the following central question. Compared to single-mode virtual simulation or physical experiment teaching, can a deeply integrated virtual-physical model yield significant improvements in knowledge construction, skill development, cognitive experience, innovation capability, and teaching feedback? The following sections detail the instructional design, experimental procedure, data analysis results, and subsequent discussion and future directions.

B. Methods

This study employed a quantitative controlled experimental design to evaluate the effectiveness of a practical teaching model for intelligent engineering investment. The design compared three instructional conditions: virtual simulation-based teaching, physical experiment-based teaching, and an integrated virtual-physical teaching model. A controlled experimental approach was considered appropriate because the study aimed to examine differences in learning outcomes across distinct treatment groups. The design was also grounded in experiential learning theory, which emphasizes learning through concrete experience, reflection, conceptualization, and application (Kolb, 1984). In engineering education, prior studies indicate that physical and virtual laboratories offer different but complementary learning affordances, making their integration pedagogically relevant (de Jong et al., 2013; Li & Liang, 2024).

The research procedure was conducted by assigning students in the Engineering Management Program at Central University of Finance and Economics into three groups. The first group received instruction through virtual simulation, which enabled students to explore complex investment scenarios, dynamic decision-making processes, and system-level interactions. The second group participated in physical experiments designed to strengthen foundational engineering concepts and concrete technical understanding. The third group experienced a combined virtual-physical model, in which physical experiments were used to establish basic engineering foundations, while virtual simulations were used to address complexity and management-oriented decision-making. This procedure reflects the view that virtual and physical experiments can reinforce one another when they are systematically combined in practical engineering education (de Jong et al., 2013; Abdulwahed & Nagy, 2009).

Data were collected using multidimensional questionnaires administered after the completion of the instructional intervention. The questionnaire was designed to measure students' perceived and demonstrated learning outcomes across five dimensions: knowledge construction, skill development, cognitive experience, innovation capability, and teaching feedback. These dimensions were selected to capture both cognitive and practical aspects of engineering management learning. Questionnaire-based evaluation is suitable for assessing students' learning experience, satisfaction, and instructional feedback, particularly in studies examining virtual laboratory and simulation-based learning environments (Li & Liang, 2024). The use of multiple dimensions also allowed the study to evaluate not only technical learning outcomes but also students' cognitive engagement and capacity for innovation within complex engineering investment contexts.

The collected data were analyzed using Analysis of Variance (ANOVA) to determine whether statistically significant differences existed among the three instructional groups.

ANOVA was selected because the study compared more than two groups across the same set of learning outcome dimensions. The analysis focused on identifying differences in mean scores for knowledge construction, skill development, cognitive experience, innovation capability, and teaching feedback. Before conducting ANOVA, the data should be screened for statistical assumptions, including independence of observations, normality, and homogeneity of variance. The results of the ANOVA provided empirical evidence for determining whether the integrated virtual-physical model produced stronger learning outcomes than the single-mode approaches. This analytical approach is consistent with experimental research designs that examine the effect of instructional treatments on measurable outcomes (Montgomery, 2019; Creswell & Creswell, 2018).

C. Results and Discussion

Instructional Design

The core of this design involves constructing a teaching system characterized by a physical-to-virtual, virtual-physical interaction and feedback loop. The target learners are undergraduate students in Engineering Management, with the curriculum integrating core practical components from multiple courses, including Building Architecture, Building Structures, and Comprehensive Practice in Engineering Management.

Physical Experiment Teaching Design

The physical experiment component aims to address the deficiency in engineering technology support, adhering to principles of foundational learning, engagement, and operability (Sukacké et al., 2022). It comprises three modules, as detailed in Table 1.

Table 1. Content and objectives of physical experiment teaching

Experiment Module	Specific Experiment Content	Core Teaching Objectives
Module 1. Engineering Material Cognition	<ol style="list-style-type: none"> 1. Tensile/compressive/torsional tests on mild steel and cast iron. 2. Determination of cement fineness, water requirement for normal consistency, and setting time. 3. Aggregate gradation and apparent density tests. 4. Concrete cube compressive strength test. 	Establish intuitive perception of material mechanical properties (strength, plasticity, toughness) and physical attributes. Understand the impact of material parameters on project cost and structural safety.
Module 2. Basic Component Failure Analysis	<ol style="list-style-type: none"> 1. Flexural failure tests on reinforced concrete beams (under-reinforced, over-reinforced, and lightly reinforced). 2. Failure test on axially loaded reinforced concrete columns. 	Observe failure modes and evolution processes of components with varying reinforcement ratios. Establish a causal chain understanding of "material-structure-performance" and appreciate the engineering significance of design codes.
Module 3. Structural Model Design & Fabrication	<ol style="list-style-type: none"> 1. Design and fabrication of bamboo/wood models of high-rise structures (e.g., frame-core tube) or long-span structures (e.g., trusses). 2. Static load testing of models to failure. 	Apply mechanics knowledge for reverse engineering and innovative design. Experience the relationship between load paths, joint construction, and

Experiment Module	Specific Experiment Content	Core Teaching Objectives
		overall stability through hands-on fabrication.

Virtual Simulation Teaching Design

The virtual simulation component addresses the insufficient capacity for decision-making in complex scenarios (Sacks & Pikas, 2013; Sami Ur Rehman, Abouelkhier, & Shafiq, 2023; Wang et al., 2018). Utilizing tools like Unity 3D and Revit, a virtual simulation teaching platform based on actual campus buildings was developed, including the following parts.

3D Building Modeling and Immersive Navigation. Based on BIM technology, detailed 3D models of typical buildings on the Shahe Campus (e.g., library, teaching buildings) were constructed. Wearing VR headsets, students can freely navigate the virtual interiors, examining the spatial locations, connections, and material information of structural components like beams, slabs, columns, and walls.

Complex Structure and Construction Process Simulation. This module contains two sub-functions. First, structural failure simulation models nonlinear responses of high-rise buildings under seismic or wind loads, as well as instability and collapse processes (e.g., cantilevered scaffolding failure due to loosened fasteners). Second, construction process simulation replicates complex procedures like deep excavation support and hydration heat analysis during mass concrete pours. Students can adjust construction parameters and observe impacts on schedule and cost. This module directly addresses the instructional challenge of providing access to complex and hazardous on-site engineering observations.

Dynamic Investment Cost Simulation. This module is a distinctive feature of this study, highlighting the professional strengths of engineering management within a finance and economics university context. The system links the BIM model with bills of quantities and enterprise cost databases. When students modify structural schemes or material selections within the virtual environment, the system provides real-time dynamic updates on project costs and major resource consumption, enabling integrated "technical-economic" decision-making practice.

Design of the Integrated Virtual-Physical Teaching Process

A central innovation of this study is the design of a closed-loop teaching process. This process mirrors the Experiential Learning Theory's sequence of Concrete Experience, Abstract Conceptualization, Active Experimentation, and resonates with the Conceive-Design-Implement-Operate lifecycle philosophy of the CDIO engineering education framework (Kang et al., 2025), shown as follows. Pre-class. Initial Physical Exploration. Students first conduct physical material mechanics experiments from Module 1. They personally stretch steel bars and crush concrete specimens, forming initial sensory experiences and gathering basic data about material behavior.

In-class. Virtual-Physical Synergy. The instructor presents an integrated task. For instance, Design and optimize the roof structure for a proposed new gymnasium on the Shahe Campus, requiring a 40-meter span, total cost under 5 million RMB, and ensuring safety under seismic fortification intensity 8. The following synergistic steps unfold: 1) Physical Informs Virtual: Students utilize material constitutive parameters and failure characteristics

observed in physical experiments to set reasonable boundary conditions and parameters within the virtual simulation platform. 2) Virtual Informs Physical: Students perform multi-scheme comparisons virtually. For critical joints optimized in simulation, small-scale physical model verification is conducted during the model-making module. 3) Technical-Economic Linkage: While adjusting technical solutions on the virtual platform, students simultaneously track cost variations in real time, striving to find an optimal balance between safety and economy.

Post-class. Reflection and Synthesis. Students compile experimental reports comparing the pure virtual experience with the integrated virtual-physical process. They analyze how physical perception influenced their decision quality within the virtual environment, culminating in a comprehensive engineering investment decision analysis report. This step underscores the critical role of reflective observation within the experiential learning cycle.

Teaching Experiment Design and Effectiveness Analysis

To scientifically evaluate the effectiveness of the described virtual-physical integration teaching model, a quasi-experimental study was designed.

Participants and Grouping

Participants were undergraduate students majoring in Engineering Management at the School of Management Science and Engineering, Central University of Finance and Economics, enrolled in courses between 2022 and 2025. Recognizing potential baseline knowledge differences across cohorts and to mitigate time effects, a non-equivalent control group design was adopted. Entire cohorts receiving different teaching interventions in different academic years were treated as independent samples for comparison. Group 1 (Virtual-Only Group, V-only). Taught in 2022, comprising 32 students. This group received only the virtual simulation instruction described above, without any physical experiments. Group 2 (Physical-Only Group, P-only). Taught in 2023 (28 students) and 2024 (28 students), totaling 56 students. This group received only the three-module physical experiment instruction, without access to the virtual simulation platform for complex scenario analysis. Group 3 (Virtual-Physical Combined Group, V+P). Taught in 2025, comprising 24 students. This group received the complete physical-to-virtual, virtual-physical integrated teaching model described in Section 2.

No significant differences ($p > 0.05$) were found among the three groups regarding university entrance scores or average grade points in prerequisite courses (e.g., Engineering Mechanics, Introduction to Construction Engineering), suggesting group homogeneity. One-way Analysis of Variance (ANOVA) was employed to compare performance differences across multiple learning dimensions among the three groups, thereby testing the differential effects of the teaching models.

Measurement Instruments and Data Collection

The measurement instrument was a questionnaire containing 18 items rated on a 5-point Likert scale and one multiple-choice question (see Appendix). It covered five core dimensions, including Knowledge Construction (4 items), Skill Development (4 items), Cognitive Experience (4 items), Innovation Capability (3 items), and Teaching Feedback (3 items). All students completed the questionnaire online anonymously immediately upon course completion. A total of 112 questionnaires were distributed, with 112 valid responses received (100% effective response rate). Cronbach's α coefficients for the questionnaire dimensions ranged from 0.86 to 0.92, indicating good internal consistency reliability.

Analysis of Experimental Results

ANOVA was used to test for significant differences among the three groups regarding total scores and scores across the five dimensions. When ANOVA results were significant, Tukey HSD post-hoc tests were conducted for pairwise comparisons. The significance level was set at $\alpha = 0.05$.

(1) Descriptive Statistics

Table 2 presents the means and standard deviations for each group across the assessed dimensions. The results clearly show that the Virtual-Physical Combined Group (V+P) achieved the highest mean scores across all indicators, accompanied by relatively smaller standard deviations. This indicates not only superior learning outcomes for this group but also greater stability in teaching effectiveness, with less individual variation among students.

Table 2. Descriptive statistics of student ability dimension scores by teaching mode (mean \pm Standard deviation)

Dimension (Total Score)	Virtual-Only (V-only, N=32)	Physical-Only (P-only, N=56)	Combined Group (V+P, N=24)
Knowledge Construction (20)	14.22 \pm 2.58	15.89 \pm 2.21	18.13 \pm 1.54
Skill Development (20)	15.06 \pm 2.31	14.04 \pm 2.65	18.42 \pm 1.32
Cognitive Experience (20)	15.91 \pm 2.02	14.52 \pm 2.49	18.75 \pm 1.21
Innovation Capability (15)	10.59 \pm 1.98	10.29 \pm 2.15	13.67 \pm 1.01
Teaching Feedback (15)	11.31 \pm 2.10	10.89 \pm 2.33	13.92 \pm 0.93

(2) Results of ANOVA

The one-way ANOVA results (Table 3) indicate highly significant differences ($p < 0.001$) among the three groups across all five dimensions. This confirms that the different teaching models produced significantly divergent impacts on student learning outcomes. Notably, the Skill Development dimension yielded the highest F-value ($F = 32.41$, $p < 0.001$), underscoring that the combined model's most pronounced effect was on enhancing practical skills.

Table 3. One-way ANOVA results for dimensions and total score

Dimension	Source of Variation	Sum of Squares (SS)	df	Mean Square (MS)	F value	p value
Knowledge Construction	Between Groups	264.52	2	132.26	26.15	<0.001
	Within Groups	551.48	109	5.06		
Skill Development	Between Groups	337.68	2	168.84	32.41	<0.001
	Within Groups	567.32	109	5.21		
Cognitive Experience	Between Groups	317.75	2	158.88	29.78	<0.001
	Within Groups	581.25	109	5.33		
Innovation Capability	Between Groups	187.43	2	93.72	26.94	<0.001
	Within Groups	379.57	109	3.48		
Teaching Feedback	Between Groups	142.89	2	71.45	19.87	<0.001
	Within Groups	392.11	109	3.60		

(3) Post-Hoc Analysis (Tukey HSD)

The Tukey HSD post-hoc test results (Table 4) further elucidate the specific sources of intergroup differences. Differences between the V+P group and the V-only group, as well as

between the V+P group and the P-only group, were highly significant ($p < 0.001$) across all dimensions and total scores. This signifies that the integrated model comprehensively outperformed either single-mode approach. This finding aligns closely with the meta-analysis by comparing learning outcomes in non-traditional versus traditional laboratories.

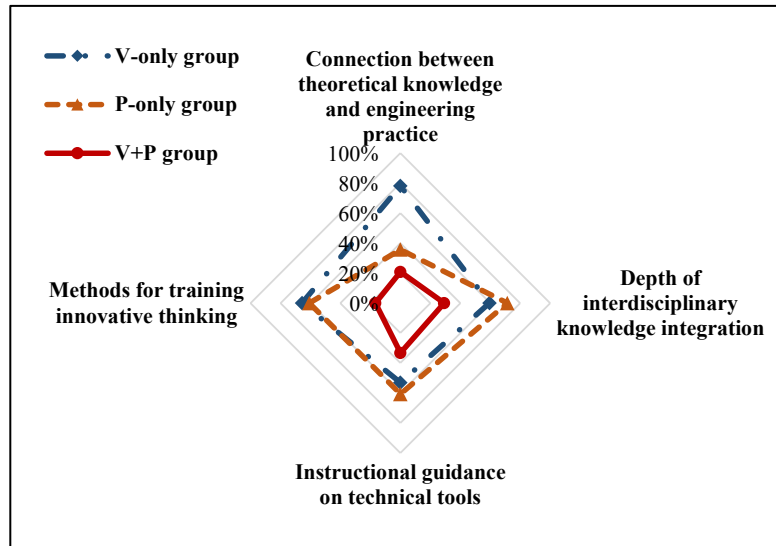
Furthermore, while the total score difference between the V-only and P-only groups was not significant ($p = 0.654$), notable distinctions emerged in specific dimensions: The P-only group significantly outperformed the V-only group in Knowledge Construction ($p = 0.012$), whereas the V-only group showed significant advantages in Skill Development ($p = 0.048$) and Cognitive Experience ($p = 0.019$). This finding reveals the complementary nature of the two teaching modes. Physical experiments appear more effective for fostering a deep understanding of engineering fundamentals, while virtual simulation excels in cultivating technical operation skills and spatial cognition. This provides direct evidence for the necessity of integration. By combining both approaches, students can leverage the unique strengths of each mode, achieving a synergistic advantage.

Table 4. Post-Hoc test results (Tukey HSD) for total score

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	p value	95% Confidence Interval
Virtual-Only	Physical-Only	1.46	1.71	0.654	[-2.56, 5.48]
Virtual-Only	Combined Group	-15.79	1.99	<0.001	[-20.48, -11.10]
Physical-Only	Combined Group	-17.25	1.80	<0.001	[-21.48, -13.02]

(4) Analysis of Open-Ended Suggestions

Analysis of responses to the multiple-choice question (Item 19) is summarized in Figure 3. Students in the V-only group identified "Connection between theoretical knowledge and engineering practice" (78.1%) and "Methods for training innovative thinking" (65.6%) as the most critical areas for improvement. This reflects the challenge in virtual-only settings of establishing deep theoretical-practical linkages despite acquiring operational skills. The P-only group most frequently cited "Depth of interdisciplinary knowledge integration" (71.4%) and "Instructional guidance on technical tools" (60.7%). This highlights a limitation of purely physical labs. Students gain hands-on experience but lack systematic training in integrating technical operations with economic management factors like cost and risk. In contrast, the V+P group showed markedly lower selection rates across all improvement options, with the demand for improvements in "Theory-practice connection" and "Interdisciplinary integration" dropping substantially to 20.8% and 16.7%, respectively. These results corroborate the quantitative findings and provide further confirmation of the integrated model's effectiveness.



Graph 1. Radar chart of curriculum improvement needs by teaching mode

Multifaceted Advantages and Mechanisms of the Virtual-Physical Integration Teaching Model

Through a rigorously designed controlled experiment within the context of an engineering management program at a finance and economics university, this study quantitatively validates the pedagogical effectiveness of deeply integrating virtual simulation with physical experimentation. The results unequivocally demonstrate the overwhelming superiority of the combined model in fostering holistic student development. Its underlying mechanisms can be elucidated from cognitive psychology and pedagogical perspectives.

First, virtual-physical integration promotes the formation of embodied cognition. Pure virtual simulation lacks physical interaction. Relying solely on visual and auditory cues, students struggle to develop muscle memory or an intuitive understanding of mechanical concepts like material stiffness or fracture energy. As noted by Burleson et al. (2018), combined virtual-physical approaches effectively enhance students' conceptual understanding of scientific principles. The resistance felt while manually pulling a steel bar or the startling moment a concrete cube shatters during physical experimentation creates profound, indelible cognitive schemas. These embodied experiences are subconsciously activated during subsequent virtual decision-making, guiding students toward choices that align better with physical reality. This explains why the V+P group scored significantly higher on items related to perceived relevance of knowledge application scenarios (Item 11) and engineering risk anticipation ability (Item 15) compared to the V-only group.

Second, virtual-physical integration constructs a closed-loop pathway connecting lower-order and higher-order cognition. Physical experiments often involve lower-order cognition focused on individual components or materials. Conversely, engineering investment decisions represent a quintessential higher-order cognitive activity requiring multi-factor trade-offs. The integrated model enables students to input the lower-order rules and parameters derived from physical experiments as constraints and variables into the virtual simulation environment, a cognitive incubator for exploration and trial-and-error. Students can safely and cost-effectively simulate scenarios. This allows them to navigate complex problems, achieving a cognitive leap from concrete to abstract and from analysis

to synthesis. This accounts for the V+P group's exceptional performance in unconventional problem-solving ability (Item 13) and engineering scheme optimization capability (Item 8).

Third, virtual-physical integration achieves effective synthesis of technical-economic decision-making. This is a core concern for engineering management programs within finance and economics universities. Pure physical labs rarely link directly to cost data, and cost estimates in pure virtual simulations lack credibility without physical validation. In this model, physical experiments provide foundational data on real-world material waste, labor hours, etc. The virtual simulation platform then dynamically links this information with cost databases. Consequently, students directly observe the economic ripple effects triggered by each technical parameter adjustment. This immediate feedback mechanism substantially reinforces cost consciousness and investment decision-making acumen. It fundamentally explains why students in the V+P group reported the strongest perceived enhancement of professional competence (Item 18) within the Teaching Feedback dimension.

A Distinctive Pathway for Engineering Practice Teaching in Finance and Economics Universities

A significant ancillary contribution of this research is the delineation of a clear and feasible pathway for finance and economics universities to leverage strengths and shore up weaknesses in engineering practice education. For finance and economics universities, the unique positioning of engineering practice teaching should not be to cultivate pure technical engineers but rather to develop management professionals with robust engineering intuition.

Shoring up Weaknesses. Physical experiments should prioritize foundational learning, engagement, and operability. It is neither feasible nor necessary for finance and economics universities to establish large-scale industrial-grade civil engineering laboratories. This study's practice demonstrates that focusing on small but impactful physical experiment modules, such as fundamental material mechanics, standard component failure modes, and small-scale model fabrication, is sufficient to achieve the core objectives of establishing engineering intuition and comprehending physical principles. Furthermore, establishing resource-sharing alliances with neighboring strong engineering universities provides a strategic shortcut to overcoming hardware limitations.

Leveraging Strengths. Virtual simulation should focus on the deep integration of complex scenarios with management elements. Virtual simulation in a finance and economics context should transcend being a mere digital replica of engineering lab exercises. It should evolve into a strategic simulator that inherently incorporates economic and management decision-making factors like investment, cost, risk, and sustainability. This study deliberately prioritized functions such as dynamic cost calculation and risk-based scheme comparison as core features of the virtual simulation, rather than treating them as mere add-ons to structural analysis. This approach ensures that while students engage with engineering technology, their core competency in economic management is simultaneously exercised, truly embodying the essence of engineering management as opposed to pure engineering.

In summary, an ideal engineering practice teaching system for finance and economics universities should be structured as follows: Physical experiments serve as the "cornerstone," solidifying students' engineering perception; virtual simulation acts as the "engine," driving their complex decision-making abilities; and economic and managerial analysis functions as the "central thread," weaving through all practical activities.

D. Conclusion

This study addresses the pressing need for compound engineering management talent in the context of New Infrastructure development. It tackles the inherent paradox faced by finance and economics universities in engineering practice education, insufficient technical foundation versus high demands for decision-making competence. This study proposed and empirically validated a practical teaching model for engineering intelligent investment that deeply integrates virtual simulation and physical experimentation. Through a four-year controlled teaching experiment, the following conclusions are drawn. First, this integrated model significantly outperforms both pure virtual simulation and pure physical experiment modes across all measured dimensions: knowledge construction, skill development, cognitive experience, innovation capability, and teaching feedback. Second, its effectiveness stems from a productive interplay between embodied cognition and higher-order cognition, where physical engagement provides a perceptual foundation and virtual environments empower complex decision-making. Third, a distinctive pathway for finance and economics universities has been identified, foundational physical experiments, complex management-oriented virtual simulation, and cross-university resource sharing.

Despite these positive outcomes, this study has limitations and suggests avenues for future research. First, the sample size was relatively modest, and participants were not fully randomized. Future studies could involve larger-scale, multi-year, and multi-institutional randomized controlled trials to enhance the generalizability of the findings. Second, the current effectiveness evaluation relies primarily on self-report measures. Future research could incorporate process-oriented data (e.g., operation logs and decision paths from the virtual simulation platform) and objective competency tests (e.g., standardized engineering decision-making assessments) to enable more precise learning analytics. Finally, with the maturation of generative AI and digital twin technologies, the future of virtual-physical integration may evolve toward virtual-physical symbiosis. Future work could explore the construction of an intelligent teaching environment characterized by real-time mapping of physical experiments and dynamic calibration of virtual models. For instance, sensor data from physical experiments could drive real-time updates to material constitutive parameters within the virtual model. This would ensure that every virtual decision made by a student is grounded in the most current real-world data, thereby realizing a new paradigm for engineering management education that is real-time informed, authentically validated, and immediately applicable.

Acknowledgment

This work is funded by Central University of Finance and Economics Education Teaching Reform Fund in 2024 (2024ZCJG5641).

References

- Abdulwahed, M., & Nagy, Z. K. (2009). Applying Kolb's experiential learning cycle for laboratory education. *Journal of Engineering Education*, 98(3), 283–294. DOI: 10.1002/j.2168-9830.2009.tb01025.x
- Beier, J. P., & Rau, M. A. (2022). Embodied learning with physical and virtual manipulatives in an intelligent tutor for chemistry. Paper presented at the International Conference on Artificial Intelligence in Education, Chamfrom

- Bhute, V. J., Inguva, P., Shah, U., & Brechtelsbauer, C. (2021). Transforming traditional teaching laboratories for effective remote delivery—A review. *Education for Chemical Engineers*, 35, 96-104. doi: <https://doi.org/10.1016/j.ece.2021.01.008>
- Brinson, J. R. (2015). Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. *Computers & Education*, 87, 218-237. doi: <https://doi.org/10.1016/j.compedu.2015.07.003>
- Burleson, W. S., Harlow, D. B., Nilsen, K. J., Perlin, K., Freed, N.,... Jensen, C. N. (2018). Active learning environments with robotic tangibles: children's physical and virtual spatial programming experiences. *IEEE Transactions on Learning Technologies*, 11(1), 96-106. doi: 10.1109/TLT.2017.2724031
- Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE.
- de Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science*, 340(6130), 305–308. DOI: 10.1126/science.1230579
- Dunmoye, I. D., Moyaki, D., Oje, A. V., Hunsu, N. J., & May, D. (2023). A scoping review of online laboratory learning outcomes in engineering education research. Paper presented at the 2023 ASEE Annual Conference & Exposition, Baltimore Convention Center, MD from <https://api.semanticscholar.org/CorpusID:267566819>
- Frank, J. A., & Kapila, V. (2017). Mixed-reality learning environments: Integrating mobile interfaces with laboratory test-beds. *Computers & Education*, 110, 88-104. doi: <https://doi.org/10.1016/j.compedu.2017.02.009>
- Hernandez, S. S., Hernandez, M. N., Camillo, B. Z., & Padilha, F. R. R. (2025). A systematic review of virtual reality applications in engineering education: methodologies, assessments, and outcomes. Paper presented at the 2025 27th Symposium on Virtual and Augmented Reality (SVR) from
- Huang, Y. (2018). Developing a three-level framework for building information modeling education in construction management. *Universal Journal of Educational Research*, 9(6), 1991-2000
- Kang, S., Chang, C., & Kim, S. (2025). A systematic review of affordance and cognitive engagement manifested through implementation. *Educational Technology & Society*, 28(2), 35-52
- Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice Hall.
- Li, J., & Liang, W. (2024). Effectiveness of virtual laboratory in engineering education: A meta-analysis. [Journal Article; Meta-Analysis]. *PLoS One*, 19(12), e0316269. doi: 10.1371/journal.pone.0316269
- Li, J., & Liang, W. (2024). Effectiveness of virtual laboratory in engineering education: A meta-analysis. *PLOS ONE*, 19(12), e0316269. DOI: 10.1371/journal.pone.0316269
- Montgomery, D. C. (2019). *Design and analysis of experiments* (10th ed.). John Wiley & Sons.
- Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V. M.,... Jovanović, K. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education*, 95, 309-327. doi: <https://doi.org/10.1016/j.compedu.2016.02.002>
- Sacks, R., & Pikas, E. (2013). Building information modeling education for construction engineering and management. I: Industry requirements, state of the art, and gap analysis. *Journal of Construction Engineering and Management*, 139(11), 4013016. doi: 10.1061/(ASCE)CO.1943-7862.0000759
- Sami Ur Rehman, M., Abouelkhier, N., & Shafiq, M. T. (2023). Exploring the effectiveness of immersive virtual reality for project scheduling in construction education. *Buildings*, 13(5), 1123. doi: 10.3390/buildings13051123

Mao,

- Sukackè, V., Guerra, A. O., Ellinger, D., Carlos, V., Petronienè, S., Gaižiūnienè, L.,... Brose, A. (2022). Towards active evidence-based learning in engineering education: A systematic literature review of PBL, PjBL, and CBL. *Sustainability*, 14(21), 13955. doi: 10.3390/su142113955
- Walsh, Y., Magana, A. J., Quintana, J., Krs, V., Coutinho, G., Berger, E.,... Benes, B. (2018). Designing a visuohaptic simulation to promote graphical representations and conceptual understanding of structural analysis. Paper presented at the 2018 IEEE Frontiers in Education Conference (FIE) from <https://doi.org/10.1109/FIE.2018.8658885>
- Wang, P., Wu, P., Wang, J., Chi, H., & Wang, X. (2018). A critical review of the use of virtual reality in construction engineering education and training. *International Journal of Environmental Research and Public Health*, 15(6), 1204. doi: 10.3390/ijerph15061204