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Exploration of Practical Teaching Reform in Systems Engineering Courses Empowered by Virtual Simulation

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Abstract: The core objective of the Systems Engineering course is to cultivate students' systematic thinking and system optimization capabilities. Its practical teaching has long been plagued by prominent problems, including inaccessible complex system scenarios in classrooms, insufficient multi-person collaborative decision-making training, and difficulties in forming closed-loop optimization iterations. Virtual simulation technology can construct low-cost, repeatable complex system scenarios, support multi-person collaborative decision-making and data-driven iterative optimization, and provide a feasible way to resolve the above dilemmas. Based on the current status of practical teaching of Systems Engineering courses in universities, this paper expounds the core value of virtual simulation in empowering curriculum teaching reform, puts forward targeted optimization countermeasures, and cultivates high-quality management talents equipped with both systematic thinking and innovative practical abilities.

Keywords: Virtual simulation; Systems Engineering; Practical teaching; Teaching optimization

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1. Introduction

As a core course for majors in Management Science and Systems Science & Engineering, the Systems Engineering course undertakes the important mission of imparting theoretical methods such as system analysis, system modeling, system evaluation, and system optimization, and cultivating students' ability to think systematically and handle complex problems comprehensively. This course covers core contents including systems and system theories, systems engineering methodology, system models and simulation, system synthesis and evaluation, and system reliability analysis, featuring strong practicality. The advantages of virtual simulation technology in large-scale scenario construction, real-time data collection, online multi-person collaboration, and immersive interaction are highly consistent with the teaching goals of Systems Engineering courses that emphasize practicality, systematicity, and collaboration, providing technical support for solving teaching pain points and improving the quality and efficiency of practical teaching [1]. Therefore, exploring the optimization path of practical teaching for Systems Engineering courses from the perspective of virtual simulation empowerment is of great significance.

2. Existing problems in practical teaching of Systems Engineering courses in universities

2.1. Disconnection between practical teaching contents and real systems

The Systems Engineering course focuses on traditional system analysis methods such as Analytic Hierarchy Process (AHP) and system dynamics simulation, as well as input-output analysis. Although these methods can consolidate students' theoretical foundations, most practical cases rely on artificially simplified scenarios or fragmented calculation exercises, which are far from complex system structures in the real world. Current problems addressed by systems engineering are characterized by multi-dimensional factors, dynamic changes, and coupled correlations. Traditional simplified cases fail to present the nonlinear behaviors and emergent properties of real systems. Meanwhile, comprehensive and design-oriented practical content based on virtual simulation accounts for a low proportion in the curriculum, lacking systematic and full-process practical training modules of systems engineering [2].

2.2. Lack of collaboration and iteration in practical teaching modes

Curriculum teaching is dominated by the traditional lecture mode of "teacher-led and student passive reception." In practical sessions, students mostly complete system modeling or scheme calculation as individuals, without training scenarios for multi-role collaborative decision-making [3]. Systems engineering emphasizes "overall optimality" and "multi-party trade-offs," yet the single-person operation mode cannot simulate conflicts, coordination, and trade-offs among different roles and objectives during system scheme formulation. In addition, the closed-loop design of "decision–deduction–feedback–iteration" is generally missing in practical links. Students finish and submit schemes to end the task, failing to experience the core idea of repeated trade-offs and continuous improvement in system optimization [4].

2.3. Insufficient support of practical teaching platforms and resources

Systems Engineering is a highly practical course, yet the construction of virtual-real integrated teaching platforms lags behind in actual teaching. Most practical content is simple case analysis or calculation exercises, lacking project-based practice based on high-fidelity scenarios [5]. Practical teaching resources are scarce; there is a shortage of virtual simulation platforms supporting large-scale scenario editing, synchronous multi-person deduction, and full-process data collection and backtracking. Students have limited access to practical training on real system scenarios and multi-person collaborative deduction, restricting the cultivation of students' system optimization and collaborative innovation capabilities [6].

3. Value of virtual simulation empowering practical teaching reform of Systems Engineering courses

3.1. Facilitating the construction of high-fidelity system practical scenarios

Virtual simulation technology promotes dynamic updating and scenario reconstruction of practical content for Systems Engineering courses, breaking the limitations of traditional simplified cases. Relying on virtual simulation platforms to construct digital twin scenarios of complex systems, teachers and students can design comprehensive practical projects covering the whole process of system analysis, modeling, evaluation, and optimization [7]. With the editable capability of virtual simulation scenarios, real system cases in fields such as supply chain network optimization, transportation system scheduling, and public safety emergency management can be integrated into teaching. Practical teaching contents can keep pace with disciplinary frontiers and industrial practical demands, broadening students' horizons of systematic thinking [8].

3.2. Realizing multi-person collaborative and immersive training

Virtual simulation technology provides technical support for the innovation of practical teaching modes, transforming traditional single-person computational practice into multi-person collaborative and immersive system decision-making training. Teachers can organize group collaborative deduction via online multi-user systems. Students take roles such as system architect, data analyst, and decision coordinator, and jointly complete system scheme design, deduction, and evaluation in virtual scenarios to receive training on multi-role collaborative decision-making [9]. Adopting virtual reality and real-time data synchronization technologies to build immersive system evolution scenarios, in-depth collaborative deduction analysis, instant scheme comparison, and feedback response can be carried out to stimulate students' participation enthusiasm and guide them to think from the perspective of the whole system, enhancing their systematic thinking ability [10].

3.3. Cultivating students' capabilities in system optimization and data-driven decision-making

Virtual simulation empowerment solves the problem of no iteration in practical links and builds an integrated practical teaching system of "Theory + Deduction + Evaluation + Iteration," comprehensively improving students' system optimization capabilities. Virtual-real integrated practical platforms are built to simulate real system scenarios, including urban traffic flow optimization, supply chain inventory control, and emergency resource scheduling. Students conduct full-process practical training on system modeling, scheme deduction, efficiency evaluation, and iterative optimization in immersive environments to master data-driven system decision-making methods, making up for the shortcomings of unreproducible and non-interventible real system scenarios [11]. By introducing data from real system projects and acquiring behavioral data and result feedback of the whole deduction process through virtual simulation platforms, teachers can organize students to carry out multiple rounds of project practice of "Design–Deduction–Evaluation–Optimization," cultivating students' data-driven system optimization and teamwork capabilities [12].

4. Optimization countermeasures for practical teaching of Systems Engineering courses empowered by virtual simulation

4.1. Reconstructing practical teaching contents and building a virtual-real integrated training system

In optimizing practical teaching contents, teachers shall re-integrate practical contents based on curriculum positioning and talent training objectives, following the principles of consolidating foundations, strengthening comprehensiveness, and highlighting systematicity.

First, optimize basic verification experiments. Core basic training items, including verification of fundamental system dynamics models and AHP calculation, shall be retained to consolidate students' mastery of basic methods [13].

Second, add comprehensive design-oriented virtual simulation projects. Develop comprehensive practical projects covering the full chain of "System Analysis–System Modeling–Simulation Deduction–Efficiency Evaluation–Scheme Optimization" relying on virtual simulation platforms to guide students to complete the whole process of systems engineering practice from demand analysis to scheme optimization.

Third, introduce real system case libraries. Sort out representative system cases in fields such as urban traffic management, supply chain collaboration, and emergency scheduling, and transform them into editable, deducible, and iterative virtual simulation teaching projects. Students are guided to compare differences of system schemes under various scenarios to form a practical teaching content system integrating basics, comprehensive modules, and frontier topics [14].

4.2. Innovating practical teaching modes and building online multi-person collaborative deduction classrooms

In practical teaching, teachers shall adopt virtual simulation technology to innovate teaching methods. First, implement a hybrid practical mode of "online editing + offline deduction." The platform releases scenario construction tasks and pre-learning materials before class to guide students to get familiar with system logic in advance.

Second, introduce online multi-person collaborative deduction into classroom teaching. Students are divided into groups to take different system roles in virtual scenarios and jointly complete scheme design, deduction implementation, and result analysis.

Third, carry out data-driven iterative training. Students conduct quantitative analysis and problem diagnosis on deduction results with system evaluation methods, adjust schemes, and proceed to the next round of deduction. Through multiple iterations, students can understand that system optimization is a continuous improvement process [15].

Take the teaching session of system dynamics in the module "System Models and Simulation" as an example. Before class, teachers upload daily passenger flow data and emergency evacuation records of a subway station to the platform. Students complete system boundary definition and identification of key variables accordingly. During class, the platform dynamically displays the evolution of passenger density and evacuation duration under different evacuation strategies. Students are divided into groups for modeling tasks. Each group establishes causal feedback models of subway evacuation with system dynamics methods, determines functional relationships among key variables, and carries out multi-scenario simulation by adjusting parameters such as escalator operation directions, gate opening quantities, and broadcast guidance strategies. Differences in system behaviors of various schemes are compared through online multi-person deduction, and comprehensive optimization schemes are proposed. The platform automatically records modeling processes and parameter adjustment paths and generates model evaluation reports. Teachers check the progress of each group in real time via large data screens and deliver centralized lectures on common modeling errors. After class, the system generates student learning portraits based on deduction data and pushes targeted exercises. This mode integrates virtual simulation into teaching and realizes the shift from teacher demonstration of models to student construction of systems.

4.3. Improving practical teaching platforms and support systems

To boost practical teaching effectiveness, universities shall increase investment in the construction of virtual simulation practical platforms and perfect supporting systems. First, build a virtual-real integrated practical teaching platform for systems engineering. The platform shall possess core functions including scenario editing, synchronous online multi-person deduction, full-process data collection and analysis, and multi-terminal access, supporting independent design of system scenarios by teachers and inquiry-based learning by students. Second, establish supporting practical teaching resource libraries. Develop or introduce virtual simulation case libraries, model libraries, and databases covering various fields to ensure rich and cutting-edge practical teaching content. Third, perfect practical assessment mechanisms and formulate multi-dimensional evaluation criteria. Indicators including scheme design quality, performance in deduction processes, iterative optimization effects, and teamwork capabilities shall be incorporated into assessment, and practical scores shall account for a reasonable proportion of the total course grade to raise students' attention to practical links and guarantee the actual effects of virtual-real integrated practical teaching.

5. Conclusion

As a core course for majors in Management Science and Systems Science & Engineering, Systems Engineering plays a vital role in cultivating high-quality management talents with systematic thinking and comprehensive decision-making capabilities. The rapid development of virtual simulation technology brings brand-new opportunities and technical support to resolve pain points in traditional practical teaching and promote the high-quality development of curriculum practical teaching. In optimizing curriculum practical teaching, teachers shall take talent training objectives as the orientation and adopt multiple measures, including reconstructing practical teaching contents, innovating online multi-person collaborative deduction modes, perfecting virtual-real integrated practical platforms, and strengthening faculty construction to realize deep integration of virtual simulation technology and practical teaching of Systems Engineering courses, and coordinate the cultivation of professional capabilities and systematic thinking. The overall quality of practical teaching will be improved to cultivate high-quality talents with a solid theoretical foundation in systems, virtual simulation application ability, collaborative innovation literacy, and system optimization thinking. In follow-up work, universities and teachers shall continue to deepen research on the integration of virtual simulation technology and Systems Engineering teaching, continuously optimize teaching design, and contribute to talent cultivation.

Disclosure statement

The author declares no conflict of interest.

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