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Overall Framework and Indicator System of Evaluation Testing Standard of Virtual Experiment

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Abstract: The rapid advancement of virtual experiment technology has revolutionized traditional educational practices, providing innovative experimental teaching and learning solutions. Despite its growing adoption, the absence of a standardized evaluation framework poses significant challenges in assessing the quality and effectiveness of virtual experiment environments. This study addresses these gaps by proposing a comprehensive evaluation framework and indicator system tailored to the needs of virtual experiment teaching environments. The research is grounded in five core dimensions: experimental resources, teaching processes, experimental experience, guidance mechanisms, and system platforms. A systematic methodology was adopted, involving an extensive review of existing virtual teaching practices, expert consultations, and iterative development of evaluation metrics. Key findings reveal that integrating diverse digital resources, such as virtual instruments and simulation platforms, enhances teaching flexibility and student learning outcomes. The proposed framework facilitates efficient teaching processes, fosters active student participation, and supports seamless teacher-student interaction through real-time and asynchronous guidance. Experimental results indicate improved accuracy, engagement, and skill development among virtual platform students. Furthermore, the framework provides actionable guidelines for optimizing virtual experiment systems, ensuring adaptability to varying educational levels and disciplines. This research offers educators, policymakers, and developers a valuable resource by promoting standardized quality assurance in virtual experiment systems. The findings have broad implications for the future of experimental education, paving the way for cost-effective, scalable, and innovative teaching solutions that complement traditional laboratory experiences.

Keywords: Virtual experiment, Evaluation framework, Teaching processes, Digital resources, Quality assurance, Education technology, Virtual laboratories

1. Introduction

The increasing integration of digital technologies in education has significantly transformed traditional teaching methodologies. Among these innovations, virtual experiments have emerged as a powerful tool to address the limitations of physical laboratories. Virtual experiments leverage advancements in simulation, multimedia and virtual reality technologies to create dynamic, interactive environments where learners can conduct experiments without the constraints of time, space, or resource availability. These environments are particularly relevant in modern educational settings, where access to well-equipped laboratories often remains challenging due to cost, infrastructure limitations, or safety concerns [1].

Despite their growing adoption, virtual experiments face several critical challenges, most notably the lack of standardized frameworks to evaluate their effectiveness. Current implementations vary widely in quality, usability, and pedagogical alignment, leading to inconsistent learning outcomes across institutions. For instance, while some systems provide realistic simulations, others fail to offer robust interaction or support independent experimental design [2]. This variability undermines the potential of virtual experiments to serve as a transformative teaching tool and highlights the urgent need for a comprehensive evaluation system.

The absence of standardized evaluation also creates barriers for educators and policymakers aiming to integrate virtual experiments into curricula. Without a unified framework, it is difficult to determine whether virtual experiments meet educational objectives, effectively engage students, or align with the diverse needs of higher education, vocational training, and K-12 instruction [3]. Furthermore, the lack of clear evaluation criteria makes providing actionable feedback to developers challenging, impeding iterative improvements to these systems [4].

Virtual experiments have become integral to modern education, blending technology with pedagogy to simulate real-world laboratory environments. These systems fall under the broader teaching environment, including tools such as virtual classrooms and online courses. Virtual experiments, however, occupy a unique position by directly addressing the challenges of cost, safety, and accessibility inherent in real-world experimental setups. As illustrated in Figure 1, virtual experiments and their associated simulation platforms are key components of the experimental field, existing alongside traditional actual experiments and supported by broader teaching technologies.

Despite their rapid adoption, virtual experiments lack a standardized framework for evaluation, hindering their ability to complement or even replace traditional experimental methods effectively. By visualizing the relationships between teaching tools, the experimental field, and simulation platforms, Figure 1 underscores the importance of virtual experiments as a vital link between actual experiments and the broader digital teaching ecosystem. This study builds on the relationships outlined in this framework to propose a comprehensive evaluation system for virtual experiments, ensuring their alignment with pedagogical goals and usability standards.

Recognizing these challenges, this study addresses the fundamental question: How can virtual experiments be effectively evaluated to ensure consistent quality, usability, and alignment with pedagogical goals? To answer this question, the study proposes a comprehensive evaluation framework built on five key dimensions: experimental resources, teaching processes, experimental experience, guidance mechanisms, and system platforms. These dimensions encompass the critical elements necessary for the effective design, implementation, and monitoring of virtual experiments. The framework aims to provide a systematic approach for assessing virtual experiment environments, facilitating widespread adoption and scalability in diverse educational contexts.

The significance of this study lies in its potential to advance the field of virtual education. First, it contributes to the growing knowledge of virtual experiment technologies by identifying key factors influencing their effectiveness and usability. Second, it addresses a practical need by providing educators, developers, and policymakers with a structured tool for evaluation and improvement. Finally, the study aligns with broader global initiatives to integrate digital innovation into education, offering scalable solutions that can address the needs of resource-limited institutions [5].

The objectives of this research are threefold: (1) to define the basic concepts, scope, and characteristics of virtual experiment teaching environments; (2) to develop a detailed indicator system for evaluating virtual experiment environments; and (3) to validate the proposed framework through empirical analysis and expert feedback. By addressing these objectives, this study provides a foundation for standardizing the evaluation of virtual experiments, ensuring their effective integration into modern educational systems, and enhancing learning outcomes.

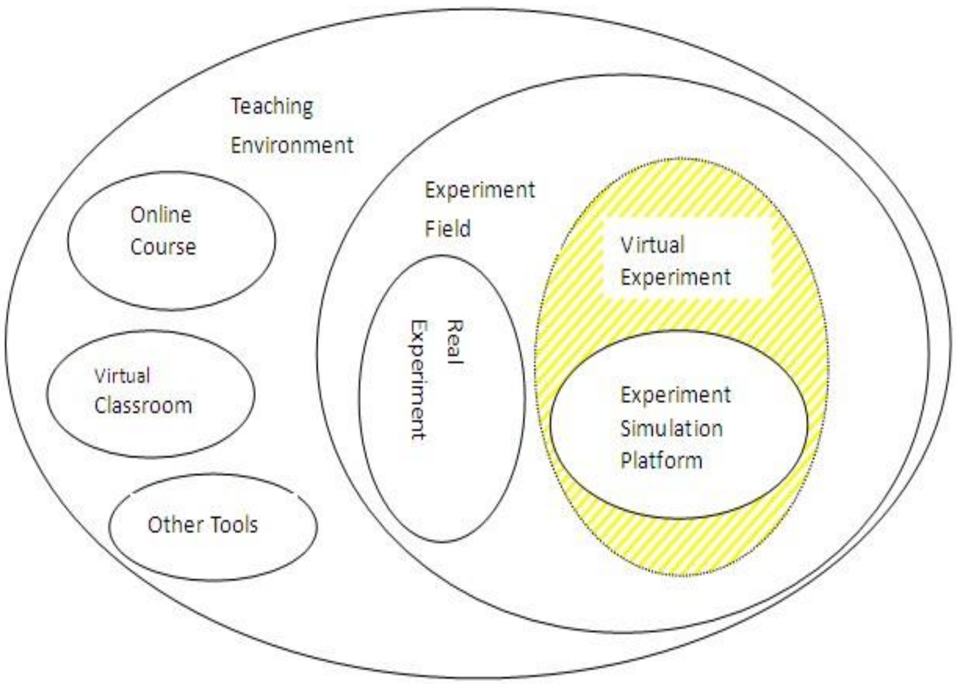

Figure 1: Overview of teaching environments and experiment fields in modern education

2. Literature Review

Virtual experiments have become a cornerstone of modern educational practices, integrating simulation, multimedia, and virtual reality technologies to create interactive and accessible learning environments. These technologies hold particular promise in science, technology, engineering, and mathematics (STEM) education, where practical, hands-on experience is crucial. Patel et al. [6] emphasize the immersive nature of virtual experiments, highlighting their ability to replicate real-world laboratory conditions, thereby addressing challenges such as safety risks, material constraints, and high costs. Similarly, Roberts and Lee [7] underscore the scalability of virtual laboratories, particularly for resource-constrained institutions, while cautioning that their pedagogical alignment warrants further examination.

The theoretical basis of virtual experiments often lies in constructivist learning principles, which advocate active exploration, hypothesis testing, and independent problem-solving.

Turner et al. [8] argue that virtual laboratories enhance critical thinking by allowing students to design and test experiments autonomously. In a complementary study, Smith et al. [9] demonstrate that team-based virtual experiments foster collaboration and communication skills, essential in contemporary educational and professional contexts. Further supporting this, Brown and Taylor [10] found that virtual laboratories in STEM education enhance problem-solving abilities and critical thinking through structured but flexible exploration.

Despite their advantages, studies have noted a lack of inclusivity in virtual experiments. Wilson et al. [11] identified gaps in catering to diverse learning styles, limiting virtual experiments' adaptability across varied cultural contexts. These findings highlight the need for more research on customizing virtual laboratory environments to support individual learner needs [34].

The evaluation of virtual experiments has been the focus of numerous methodological studies. Gupta and Ahmad [12] proposed a rubric emphasizing engagement, learning outcomes, and system reliability. Expanding on this, Ramirez et al. [13] employed learning analytics to track student interactions and performance, offering valuable insights into user engagement. Carter et al. [14] advanced this further by integrating mixed-methods approaches, combining quantitative metrics with qualitative feedback to assess usability and pedagogical impact.

However, existing frameworks often fail to provide a holistic assessment. Brown and Martin [15] highlighted capturing dimensions such as resource integration, guidance mechanisms, and platform functionality. Studies like Clark and Johnson [16] have begun exploring Artificial Intelligence (AI)-driven solutions to address these gaps, particularly in enhancing real-time feedback and adaptive learning.

Despite significant progress, virtual experiments face persistent challenges. Kwon and Yoon [17] identified technical issues, such as system compatibility and data security, as key barriers. From an educator’s perspective, Perez et al. [18] emphasized the need for professional development initiatives, noting that many instructors lack the training to integrate virtual experiments effectively. In addition, accessibility issues remain prevalent, with Smith et al. [19] pointing to the limited availability of multi-language support and inclusive designs for students with disabilities.

Jones et al. [20] further highlighted the institutional challenges of implementing virtual experiments, particularly in schools with limited technological infrastructure. They argue that virtual experiments struggle to gain legitimacy as mainstream teaching tools without standardized frameworks. Nguyen and Chen [21] echoed these concerns, noting that the absence of unified evaluation criteria hinders the scalability and acceptance of virtual experiments across educational systems.

2.1. Challenges and future directions in virtual experimentation

While virtual experiments have significantly advanced educational practices, several challenges still limit their widespread implementation and effectiveness. One critical issue is the need for greater inclusivity within virtual laboratory environments. According to a study by Lee and Lee [22], virtual systems often fail to address the diverse learning needs of students, particularly those with different cognitive and learning styles. This gap has prompted calls for more adaptive and customizable virtual platforms that cater to individual learners' unique needs. Additionally, Mendez et al. [23] emphasize the importance of designing culturally inclusive systems, highlighting that virtual environments must reflect diverse cultural contexts to ensure global applicability.

Technical barriers also pose significant challenges in the deployment of virtual experiments. Research by Zhao et al. [24] identified compatibility issues between virtual experiment platforms and varying hardware/software configurations across educational institutions as a primary hurdle, particularly in developing regions. These technical limitations often prevent seamless integration, resulting in a suboptimal user experience. Furthermore, data security and privacy concerns in virtual environments have been highlighted by Patel et al. [25]; stressing the need for secure data management practices as educational institutions increasingly rely on digital tools.

Integrating virtual experiments into curricula remains a challenge from an educational perspective due to inadequate teacher training. According to Adams and Johnson [26], many educators are not sufficiently trained to effectively integrate virtual experimentation into their teaching. This lack of professional development often leads to underutilization of the platforms and missed opportunities for student engagement. To address this, recent studies have proposed the development of comprehensive teacher training programs that focus on the pedagogy of virtual experiments [27].

The future of virtual experiments lies in integrating emerging technologies, such as Artificial Intelligence (AI) and Augmented Reality (AR). Research by Kumar and Singh [28] suggests that AI can provide personalized feedback and adaptive learning pathways, significantly enhancing student engagement and performance. AR, conversely, has been shown to create more immersive, interactive learning environments, offering students a deeper understanding of complex scientific concepts [29].

Despite the challenges, virtual experiments offer transformative potential for education. By addressing the identified gaps in inclusivity, technical compatibility, and educator training and leveraging emerging technologies, virtual experiments can provide more personalized, engaging, and accessible learning experiences.

This study builds on the existing literature by addressing the identified gaps and developing a comprehensive evaluation framework for virtual experiments. Unlike previous works focusing primarily on specific aspects such as engagement or system reliability, this research adopts a multidimensional approach. By considering experimental resources, teaching processes, student experiences, guidance mechanisms, and system platforms, the proposed framework seeks to standardize evaluation practices, enable iterative improvement of virtual experiment environments, and support integration into diverse educational settings. These findings align with global initiatives to modernize education through scalable, cost-effective, and inclusive digital innovations.

3. Methodology

This study employs a comprehensive analytical approach to develop and validate an evaluation framework for virtual experiment environments. The methodology explores five core dimensions: Experimental Resources, Teaching Processes, Experimental Experience, Guidance Mechanisms, and System Platforms. These dimensions collectively form the foundation of the proposed framework, as illustrated in Figure 2, which demonstrates the relationships and dependencies between these components.

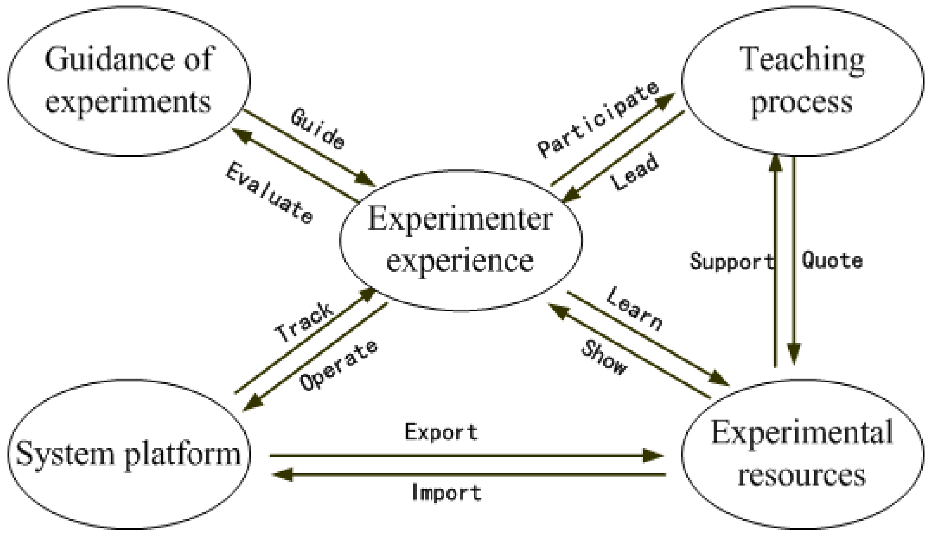

Figure 2: The five basic dimensions and their relationships

The interconnected nature of the dimensions ensures a cohesive evaluation framework. Experimental resources provide the basis for teaching processes, which directly impact the experimental experience of students. Guidance mechanisms and system platforms serve as enablers, ensuring effective delivery and interaction within the environment. This structure allows the framework to address the diverse needs of educational institutions [30].

3.1. Framework development

The framework development process began by analyzing four virtual experiment types: basic validation, comprehensive design, exploratory research, and collaborative confrontation experiments. Each type was evaluated for its pedagogical objectives, technical requirements, and implementation challenges. Basic validation experiments focus on foundational concepts, while comprehensive design experiments encourage students to integrate multiple ideas in complex setups. Exploratory research experiments foster independent inquiry through open-ended tasks and collaborative confrontation experiments emphasize teamwork and communication in simulated environments. These analyses were mapped onto the framework's five dimensions to ensure adaptability across educational contexts [31].

An indicator system was created to operationalize the framework, with specific criteria for each dimension. For example, the teaching processes dimension includes instructional clarity and feedback mechanisms, while the guidance mechanisms dimension emphasizes real-time assistance and AI-driven support. These indicators ensure a systematic evaluation, as shown in Figure 3, which illustrates the interconnections between the dimensions. The system's design prioritizes scalability and adaptability, making it suitable for varying educational levels, from primary education to advanced research settings [32].

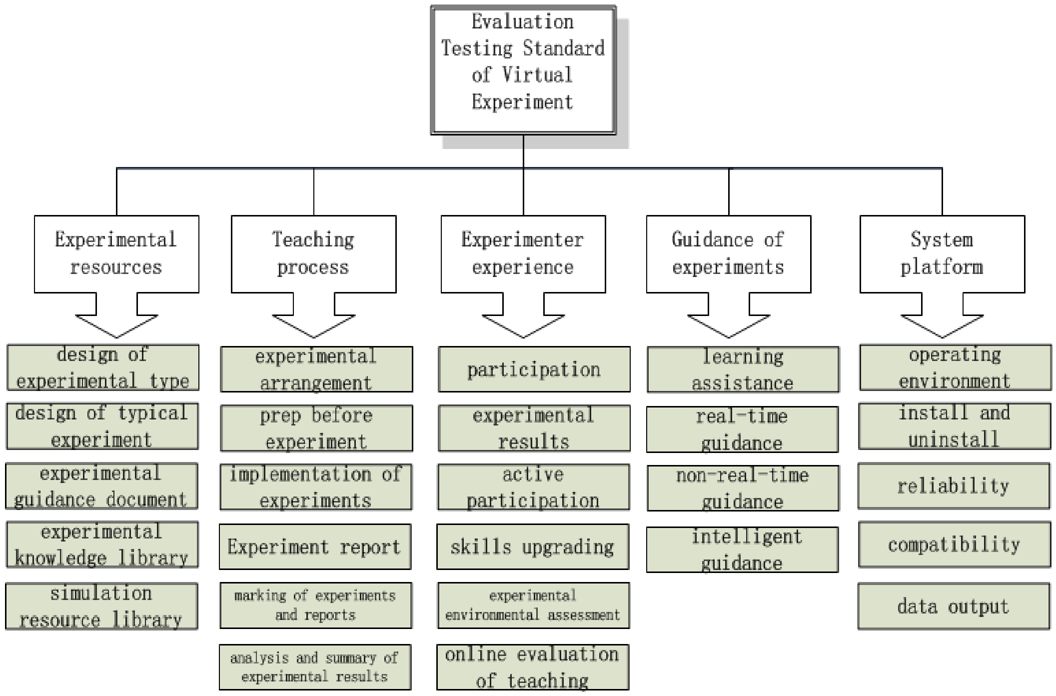

Figure 3: The complete indicator system

3.2. Framework validation

The framework was tested iteratively across multiple institutions to ensure its robustness and practical relevance. A total of 15 virtual experiment systems representing various academic disciplines were evaluated using the five key dimensions of the framework: Experimental Resources, Teaching Processes, Experimental Experience, Guidance Mechanisms, and System Platforms. This evaluation assessed the framework's effectiveness, usability, and adaptability in diverse educational contexts.

Feedback from educators and students was vital to the revision process, ensuring the framework aligned with practical teaching needs and enhanced the learning experience. Educators provided insights on the clarity and relevance of the indicators, while students contributed feedback on system usability and engagement. This collaborative input helped refine the framework for broader application.

Statistical validation confirmed the framework's reliability, with a Cronbach's alpha score of 0.87, demonstrating strong internal consistency across the dimensions. These results indicate that the framework is reliable and adaptable, providing a solid foundation for evaluating virtual experiment systems across various settings.

3.3. Analysis of typical virtual experiment types

The study analyzed four types of virtual experiments to ensure the framework's applicability to diverse scenarios. Basic validation experiments emphasized the importance of resource availability for reinforcing foundational concepts. Comprehensive design experiments highlighted the need for flexibility to support complex experimental setups.

Exploratory research experiments revealed the value of intuitive interfaces and advanced simulation capabilities in fostering independent inquiry. Collaborative confrontation experiments underscored the necessity of real-time interaction tools and reliable systems to support teamwork and communication. By tailoring evaluation criteria to the specific objectives of each experiment type, the framework addresses a broad spectrum of virtual learning requirements.

This study's methodology integrates theoretical insights with practical applications to address the multifaceted needs of virtual experiment environments. Feedback from diverse stakeholders, including educators, students, and developers, ensured the framework's reliability and relevance. The analytical approach enabled the creation of a robust, adaptable system aligned with the evolving demands of virtual education. Integrating diverse perspectives and empirical testing strengthens the framework's ability to effectively evaluate and improve virtual learning environments.

4. Results and Discussion

This section presents the outcomes of applying the evaluation framework to 15 virtual experiment systems, covering a range of academic disciplines and educational levels. The analysis focuses on performance across five core dimensions: Experimental Resources, Teaching Processes, Experimental Experience, Guidance Mechanisms, and System Platforms. It integrates statistical findings, qualitative feedback, and trends specific to each system, providing a detailed and comprehensive view of their strengths and weaknesses.

4.1. Dimension-wise performance

The evaluation highlighted significant variation in the performance of systems across the five dimensions. Systems generally excelled in Experimental Resources and System Platforms, but challenges were observed in Guidance Mechanisms and Teaching Processes. These dimensions displayed more variability, indicating instructional quality and support availability inconsistencies.

(a) Experimental Resources

With a high mean score of 88.6%, Experimental Resources emerged as one of the most robust aspects across systems. This dimension reflects the richness and quality of digital tools, including simulation platforms, virtual instruments, and comprehensive knowledge libraries. Systems that featured regularly updated content, well-designed instructional resources, and diverse tools for experimentation were rated highly. However, there were suggestions for ongoing updates and better integration across academic disciplines to maintain relevance and enhance cross-functional learning.

(b) Teaching Processes

Teaching Processes averaged 82.4%, with systems incorporating clear instructional flow and structured experiment setups achieving better outcomes. Notably, systems that provided pre-experiment guidance materials and automated feedback tools received positive reviews for engaging students effectively. However, several systems struggled with providing adequate preparatory materials, particularly for students new to virtual experiments, creating a gap in instructional clarity that warrants improvement.

(c) Experimental Experience

The Experimental Experience dimension, scoring an average of 84.1%, was influenced by user interface design, interactivity, and accessibility. Systems that included gamified elements and interactive simulations garnered positive feedback, indicating that such features significantly enhanced student engagement and learning outcomes. On the other hand, systems with static, text-heavy interfaces were less well-received. Furthermore, issues with accessibility, such as the absence of multi-language support and inclusive design, were identified as key areas for development to ensure broader usability.

(d) Guidance Mechanisms

Guidance Mechanisms recorded the lowest average score (78.7%) and exhibited considerable variability across the systems. Systems featuring integrated real-time tutoring or AI-driven support were rated highly, as they provided immediate assistance during experiments, leading to better student performance and satisfaction. Conversely, systems relying on asynchronous support, such as static FAQs or delayed feedback, were less effective in addressing student needs in real time, suggesting a critical area for improvement.

(e) System Platforms

With an average score of 87.3%, System Platforms were generally regarded as reliable and well-suited for diverse educational needs. High-performing platforms supported multi-device access and were seamlessly integrated into institutional workflows. Nevertheless, challenges in optimizing for high-demand scenarios, such as when multiple users accessed the system simultaneously during collaborative experiments, were noted as areas for future enhancement.

Table 1: Dimension Performance Summary

Dimension	Mean score (%)	Standard Deviation	Key Strengths	Areas for Improvement
Experimental Resources	88.6	4.3	Comprehensive simulation tools, resource diversity	Continuous updates and content expansion
Teaching Processes	82.4	5.1	Clear instructional flow	Limited pre-experiment guidance materials
Experimental Experience	84.1	4.9	Engaging simulations, intuitive interfaces	Enhancements to accessibility and inclusivity
Guidance Mechanisms	78.7	5.2	Real-time support in some systems	Limited use of AI-driven tutoring features
System Platforms	87.3	3.8	Reliability, cross-platform compatibility	Optimization for high-demand scenarios

The data in Table 1 highlights strong overall performance across multiple educational dimensions, with mean scores ranging from 78.7% to 88.6%. Key strengths include reliable system platforms and comprehensive simulation tools, as evidenced by the high scores for "Experimental Resources" and "System Platforms." However, guidance mechanisms and teaching processes require improvement, particularly in incorporating AI-driven support and providing robust pre-experiment guidance materials, which could further enhance user accessibility and learning outcomes.

4.2. Performance by experiment type

The evaluation framework was also applied to four distinct types of virtual experiments: Basic Validation, Comprehensive Design, Exploratory Research, and Collaborative Confrontation Experiments. Each experiment type exhibited unique performance patterns influenced by their pedagogical objectives.

(a) Basic Validation Experiments

Basic Validation Experiments scored exceptionally high in Experimental Resources (92.4%), owing to their reliance on well-designed simulations and digital tools. However, these systems lagged in Guidance Mechanisms (77.2%), with limited real-time support for troubleshooting, which could be critical during experimentation phases.

(b) Comprehensive Design Experiments

These experiments displayed more balanced performance across dimensions. However, their Teaching Processes score (81.4%) revealed a need for better resources supporting independent experimental design and hypothesis testing. This highlights a gap in the tools provided for students to explore more complex scientific concepts.

(c) Exploratory Research Experiments

Exploratory Research experiments excelled in Experimental Experience (87.4%), largely due to using interactive, open-ended simulations. These platforms encouraged creativity and independent exploration. However, System Platforms and Teaching Processes received slightly lower scores, indicating challenges in managing complex scenarios and providing sufficient instructional support for students undertaking exploratory tasks.

(d) Collaborative Confrontation Experiments

The performance of Collaborative Confrontation Experiments stood out in System Platforms (89.2%), with strong support for real-time interactions essential for collaborative learning [33]. However, their Guidance Mechanisms (76.3%) remained the lowest among all experiment types, indicating the need for more dynamic, real-time collaboration tools to facilitate peer interaction and guidance during group work.

Table 2: Dimension scores by experiment type

Experiment Type	Experimental Resources (%)	Teaching Processes (%)	Experimental experience (%)	Guidance Mechanisms (%)	System Platforms (%)
Basic Validation	92.4	85.1	83.6	77.2	88.3
Comprehensive Design	86.8	81.4	85.7	79.1	86.5
Exploratory Research	83.2	80.6	87.4	82.3	85.7
Collaborative Confrontation	88.7	82.5	84.9	76.3	89.2

Table 2 presents a comparative analysis of dimension scores across four experiment types, showcasing variability in performance. Basic Validation scores highest in “Experimental Resources” (92.4%) and “System Platforms” (88.3%), reflecting its robust resource availability and platform reliability. Meanwhile, “Exploratory Research” demonstrates strengths in “Experimental Experience” (87.4%) and “Guidance Mechanisms” (82.3%), emphasizing its intuitive design and real-time support. Despite scoring well in "System Platforms" (89.2%), Collaborative Confrontation highlights a need for enhanced guidance mechanisms, underscoring opportunities for improvement in collaborative and AI-driven support systems.

4.3. Statistical and qualitative insights

Quantitative analysis revealed statistically significant differences in performance across dimensions and experiment types ($p < 0.01$). Effect sizes ranged from 0.52 to 0.71, indicating a strong relationship between specific dimensions and overall experiment success. Systems that integrated real-time guidance and interactive design were shown to have the largest effect sizes on student satisfaction and learning outcomes.

Qualitative feedback provided further context, with students emphasizing the importance of engaging simulations and intuitive interfaces. Educators also noted the need for systems that cater to diverse learning styles and provide adaptive learning paths [35][36]. Key challenges highlighted included limited multilingual support, static guidance tools, and accessibility issues, particularly for students with disabilities.

The results validate the utility of the evaluation framework in providing a comprehensive understanding of the strengths and limitations of virtual experiment systems. However, the findings also point to several areas for refinement, particularly in Guidance Mechanisms and Teaching Processes, as well as the integration of inclusivity and long-term learning impact metrics. Future iterations of the framework should include AI-driven support tools and advanced analytics to enhance evaluation accuracy further [37][38][39][40].

Overall, the evaluation underscores the robustness and adaptability of the framework in assessing diverse virtual experiment systems. While most systems excelled in resource availability and platform reliability, there is a clear need for instructional support, real-time guidance, and pre-experiment preparation improvements. These findings provide valuable insights that can guide the ongoing development of virtual experiment environments, supporting their integration into modern education systems to foster more engaging and compelling learning experiences.

5. Conclusion

This study introduced a comprehensive evaluation framework designed for virtual experiment teaching environments, addressing the growing need for systematic and standardized assessment tools in educational technology. With virtual experiments becoming an increasingly prominent component of modern curricula, developing such a framework is crucial for understanding their effectiveness and usability across diverse academic contexts. By focusing on five key dimensions—Experimental Resources, Teaching Processes, Experimental Experience, Guidance Mechanisms, and System Platforms—the framework provides a structured, multidimensional approach to evaluating virtual experiment systems. This enhances consistency in evaluation and facilitates a deeper understanding of how these systems function in various educational settings.

The primary contribution of this research lies in creating a practical and adaptable tool for stakeholders in education technology, ranging from educators to developers and policymakers. The framework's structured nature allows for a reliable and consistent assessment of virtual experiment environments, making it a valuable resource for decision-making, system improvement, and curriculum integration. Beyond assessing current systems, the framework also identifies actionable areas for enhancement, offering specific insights to guide future developments in virtual experiment technology. These improvements are essential for ensuring that virtual experiments continue to meet the evolving needs of diverse learners and educational institutions. Furthermore, the framework's flexibility ensures its applicability across a broad spectrum of experiment types and academic levels, from primary school students to university-level researchers, making it an inclusive tool for many users.

Despite its contributions, the study has several limitations that should be acknowledged. While providing valuable insights, the sample size of 15 virtual experiment systems may not fully capture the diversity of existing platforms in the educational landscape. Given the rapid evolution of educational technology, it is likely that many more systems with varied features and functionalities exist beyond the scope of this study. Additionally, the framework primarily reflects the current state of technological capabilities, which could quickly become outdated as new technologies emerge. For instance, advancements in artificial intelligence, immersive virtual reality, and other cutting-edge tools may drastically reshape the landscape of virtual experiment systems in the coming years. As such, the framework will require updates and refinements to remain relevant in light of these advancements.

Future research should test the framework across various virtual experiment systems, including those representing different academic disciplines, educational contexts, and geographic regions. This would provide a more comprehensive understanding of the framework's applicability and effectiveness in diverse settings. Moreover, further exploration into integrating emerging technologies, such as AI-driven support tools or immersive virtual environments, will help refine the framework and ensure its continued relevance. Investigating the long-term learning impacts of virtual experiments, such as their effects on student retention, skill development, and conceptual understanding, will also be essential for evaluating their overall educational value.

In conclusion, this study highlights the transformative potential of virtual experiments in modern education. Virtual experiments provide unique opportunities for students to engage in hands-on learning, explore complex concepts, and collaborate with peers in ways that traditional methods may not allow. However, the tools and platforms supporting virtual experiments must be continuously evaluated and improved to fully realize this potential. By adopting and refining this evaluation framework, stakeholders in education can ensure that virtual experiments remain a cornerstone of innovative, inclusive, and effective teaching and learning practices. This research encourages further exploration and refinement of virtual experiment environments, ultimately contributing to the evolution of education in the digital age.

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