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Role of Computer-Based Simulations in Improving Science Education and Students' Engagement: A Systemic Review

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Abstract
This paper reviews the ways in which computer-based simulations may improve science instruction and student involvement in Indian higher education. Google Scholar, ERIC, and Research Gate were used to identify 50 papers published in between 2020 and 2024 that adhered to PRISMA standards. Following screening, five empirical papers were synthesized using the TCCM framework and fifteen articles were evaluated in their entirety. Simulations enhances conceptual knowledge, critical thinking and improve active classroom engagement during learning. And it became more dynamic and accessible due to the platforms like PhET, which were used for explaining difficult procedures of science. Furthermore, it was discovered that simulation-based learning helped students to collaborate with one another and close the gap between theory and practice by supplying a wallet-friendly replacement for actual labs. However, the research indicates considerable impediments such as insufficient teacher preparation, poor infrastructure and curriculum integration issues. To sum up, interactive simulations are a revolutionary teaching tool for tertiary education, post-secondary education, university education, college education and advanced education in India. Stronger faculty development, digital infrastructure and conformity to national education policies are needed for their successful implementation. By filling in these gaps, we can make sure that simulation-based learning develops from a teaching tool into a fundamental tactic for promoting fair, interesting, and future-ready science education.

Keywords: Computer-Based simulations, science education, students engagement

Introduction
In today's era, India is facing many challenges, especially in providing good quality education to children. With an increasing number of students, employing technology can aid in enhancing learning and teaching. Initiatives such as Digital India and Smart Classrooms have the objective of enhancing education and making it more engaging (MHRD, 2020). Education has also experienced a tremendous change with the integration of technology, as learning is now more accessible, interactive and effective. Conventional methods of teaching, which were textbook and lecture-based, have now turned into digital and experiential learning mediums. The application of computers, internet, artificial intelligence (AI), and virtual reality (VR) has

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improved students learning through hands-on activities in science. Computers are employed in schools to conduct numerous activities such as internet-based tests, virtual laboratories, and interactive classes. One such practical use is computer simulations, which make it easy for learners to comprehend complex topics such as math and science (NEP, 2020). Nevertheless, experts believed that all schools are not lacking access to technology and teachers require proper training to utilize it effectively (Gulati, 2008). Regardless of these issues, computers hold a lot of promise to enhance education in India.

Simulations in Education

Simulations help to replicate real-life situations and develop abilities without facing real-world repercussions. By using real-world computer models that simplify complex ideas, they also impart critical thinking and problem-solving abilities. Computers started to be used in classrooms as early as the 1960s. By the early 1980s, higher education institutions did not have access to computer simulations (de Jong & van Joolingen, 1998). The first available simulations were designed to assist aviation and military experts (Aldrich, 2005). The University of Colorado Boulder's PhET program offers students free and extensive exposure to cross-disciplinary interactive learning platforms in engineering, biology, chemistry, physics, mathematics, and even medicine (Wieman et al., 2008) It help them to develop their critical thinking and problem-solving skills (Cook et al., 2011).

Evolution of science education in India

Inclusion of technology into classroom instruction for ease of use in experiential learning. Kothari Commission (1964-66) emphasized the importance of practical work and the formulation of laboratory experiments to cultivate scientific thinking. Science education in India has advanced significantly. He standardized lists of school laboratory equipment as scientific instruction grew. To promote equitable education and unrestricted access to inquiry-based learning, Rural areas are most probably covered in the National Curriculum Framework (2005), which provided resources. The goals of the Rashtriya Madhyamik Shiksha Abhiyan (2009) and the CABE Committee Report (2005) were to expand training and usage of ICT (information and communication technology) in secondary school scientific instruction.

The National Education Policy (2020) has also included simulative digital learning and virtual laboratory experiences buttressed by a policy that is hands-on.

Simulation-Based Learning (SBL) is a revolutionary approach to building practical competencies and closing the gap between theoretical knowledge and practical application, particularly in ICT-based settings. SBL and computer simulations improved science learning by enhancing knowledge, thinking creatively, and problem-solving capacity.

Role of simulation in improving science education

Simulation-based learning (SBL) has demonstrated to be a potent tool for enhancing science education at Indian universities. Bhaskar et al. (2023) highlighted that simulations improve the engagement and conceptual understanding of students. Mehar and Arora (2021) illustrating how interactive simulations bring theory and practice together. The experimental groups of students performed better than those taught through traditional teaching methods. Classroom observations shown that students who were using simulations were more active and more enthusiastic.

As per Asadi et al. (2024), computer science simulations encourage critical thinking and technical adaptability. Mittal (2022), who worked on Chemistry teaching, proved that PhET simulations excel over conventional teaching in improving learning outcomes and comprehensively enhance students knowledge of intricate concepts. As Sharma and Verma (2023) say, employing simulations in physics classes enhanced students interest and engagement as well as their problem-solving capacity. They further highlight the need for long-term integration, appropriate training, and infrastructure support in order to fully achieve the objectives.

Role of simulation in student engagement

All the reviewed studies show that simulation-based learning (SBL) greatly improves student engagement in a number of science education domains in Indian universities. According to Bhaskar et al. (2023), simulations increase student participation in general science classes by making learning more dynamic and interesting. Mehar and Arora (2021) confirmed the role of simulations exhibited higher levels of enthusiasm and active involvement in students than those in traditional classrooms. According to Asadi et al. (2024), simulations in context of computer science not only helped students to develop their technical and thinking skills, but also maintained their interest. With an emphasis on chemistry education, Mittal (2022) discovered that PhET simulations aided students in visualizing difficult ideas, stimulating their interest and boosting their desire to learn. Sharma and Verma (2023) found that using simulations in physics classes increased student engagement and interest. The main findings of all studies shows that simulations successfully increase student engagement by facilitating interactive learning, creating a more engaging learning environment, scientific concepts.

Research Questions

The purpose of this review is to provide answers of the following questions:

1. How do interactive computer simulations enhance science education and student engagement in Indian higher education compared to traditional methods?
2. In what ways do simulations influence students' conceptual understanding, critical thinking, and problem-solving skills?

Methodology

The author employed a systematic literature review to ensure a structured, transparent, and unbiased approach to answering the research questions, As such, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines has been adopted to report the number of studies identified, screened, excluded with reasons, and finally included (Lame,2019).This process minimizes selection bias by considering all empirical evidence that meets predefined criteria.

Search strategy:

This review ensured a systematic approach by complying with the PRISMA standards. Included studies were on higher education that were executed in India and published between 2020 and 2024. They looked into how interactive computer simulations are applied in scientific classes and how it effect student participation. Excluded studies that were published prior to 2020, conducted outside of India, concentrated on school-level instruction, or did not utilize pertinent keywords.

Academic databases such as Google Scholar, Research Gate, and ERIC were thoroughly searched using keywords like "Simulation-Based Learning," "Interactive Computer Simulations," "Science Education," and "PhET platform". The review mostly concentrated on resources that illustrate the advantages and difficulties of incorporating simulations into science teaching, such as the Physics teaching Technology (PhET) platform and other projects. Mehar and Arora (2021), who highlighted SBL's function in promoting critical thinking, and Bhaskar et al. (2023), who addressed obstacles including faculty training and infrastructure, are two main studies that were synthesized. Asadi et al. (2024) investigated how well simulations work in technical education. To shed light on institutional initiatives to enhance simulation-based learning, policy papers such as Rashtriya Madhyamik Shiksha Abhiyan (2009) and National Education Policy (2020) were also examined.

PRISMA Table1: Selection of Studies

Criteria	Inclusion Criteria	Exclusion Criteria
Timeframe	Published between **2020 and 2024**.	Published before 2020 or after 2024.
Population	Studies conducted in **India** focusing on higher education institutions.	Studies conducted outside India or focusing on primary/secondary school education.
Focus	Studies examining the use of interactive computer simulations or SBL in science education and skill development in higher education.	Studies not addressing interactive simulations, SBL, or their educational impact.
Study Design	Experimental, quasi-experimental, or descriptive studies, including qualitative and quantitative methods.	Reviews without empirical evidence, theoretical papers, or anecdotal studies.
Outcomes	Research demonstrating improved educational outcomes, critical thinking, or problem-solving skills through SBL or simulations.	Studies with unclear or non-relevant outcomes, such as those focusing on unrelated pedagogical tools.

Source: Author's creation

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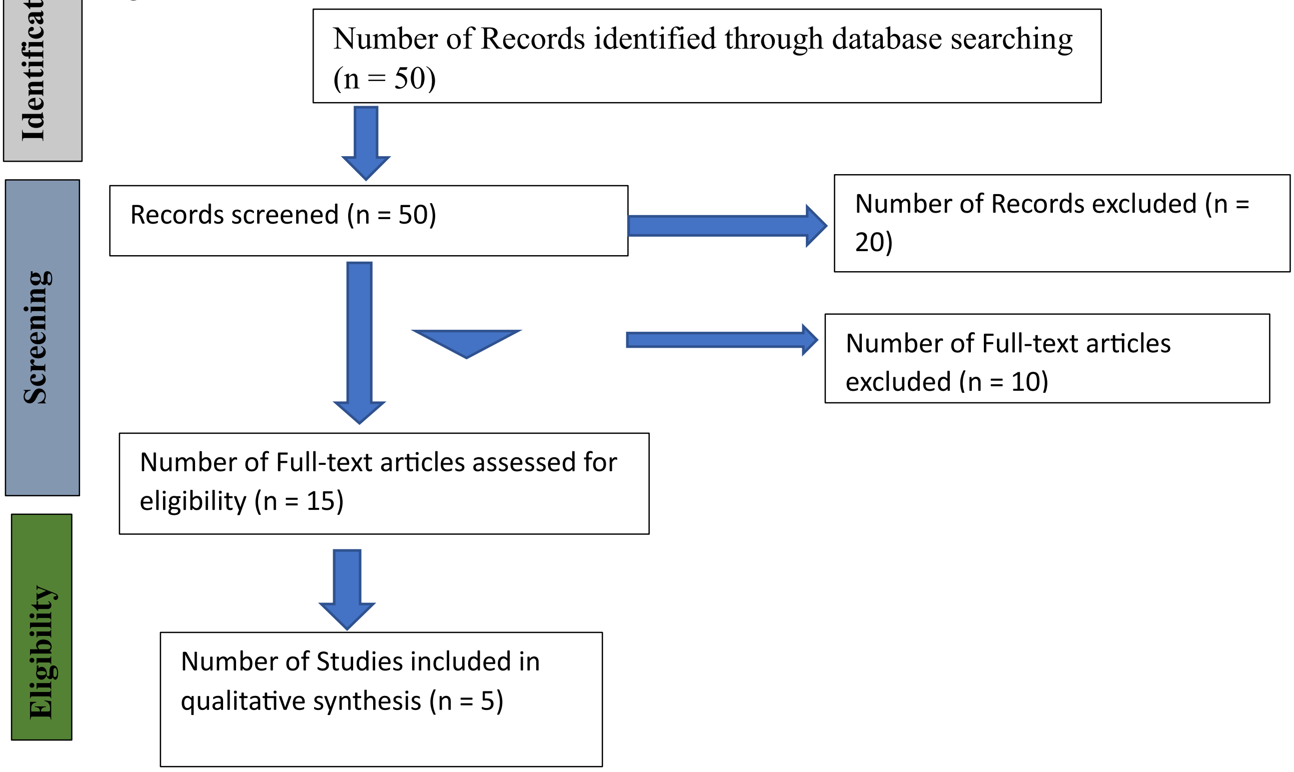
As such, literature scrutiny followed a rigorous approach to ensure comprehensive and unbiased selection. Initially, 50 articles were retrieved from the databases. Subsequently, in the screening phase, 20 articles were excluded, leaving 15 for eligibility assessment. Following full-text evaluations, 10 articles were excluded due to the defined inclusion criteria. After completing the preliminary screening and quality checks, a final set of 5 articles were selected clusion in the systematic review. The entire procedure is outlined in Figure 1.

Figure 1: PRISMA Framework



Source: Authors' creation

The researcher used TCCM (Theories-Characteristics-Contexts-Methods) framework for structuring the findings based on domain relevance (Paul et al., 2024). The Theories (T) component refers to the pedagogical frameworks such as Constructivism and Experiential learning were considered (de Jong & van Joolingen, 1998; Mehar & Arora, 2021). The **context (C)** was restricted to Indian higher education institutions, consistent with recent emphasis on technology integration in national policies (NEP, 2020; Bhaskar et al., 2023). The **characteristics (C)** focused specifically on interactive computer simulations in science education, such as PhET and similar platforms (Wieman et al., 2008; Mittal, 2022). Regarding **methodology (M),** only empirical studies published between 2020 and 2024 were included, aligning with the growing body of ICT-driven educational research (Asadi et al., 2024; Sharma & Verma, 2023). The synthesis of findings from 5 selected studies is systematically structured using the TCCM framework, as detailed in Table 2.

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Table 2: TCCM framework

Author(s) & Year	Theory (T)	Context (C)	Characteristics (C)	Methodology (M)
Mehar & Arora (2021)	Constructivism, Experiential Learning	Indian higher education (General Science Courses)	Simulation-based learning (PhET, interactive digital tools)	Quasi-experimental; compared traditional vs. simulation-based groups
Bhaskar et al. (2023)	Technology Adoption & Engagement Models	Indian Universities	Simulation-based learning in Science Classrooms	Mixed-methods; Survey + Classroom observation
Asadi et al. (2024)	Experiential & Problem-based Learning	Indian Computer Science and Networking Courses	Interactive Simulations for technical Skills Development	Longitudinal study; Experimental Research
Mittal (2022)	Constructivist Learning Approach	Indian Chemistry Education	PhET simulations for teaching complex chemical concepts	Experimental; Pre-test/Post-test design
Sharma & Verma (2023)	Active learning & Inquiry-based Learning	Indian Physics Classrooms	Simulation-based Experiments (problem-solving tasks)	Quasi-experimental; Student Performance & Engagement Measures

Results

The review of studies shows that interactive computer simulations is enhancing science education and classroom engagement in Indian higher education institutions. Most studies provides strong insights into the educational benefits and the challenges faced in implementing simulation-based learning (SBL). (Mittal, 2022; Mehar & Arora, 2021) confirm that simulations enhance comprehension of abstract and complex concepts in science. Tools such as PhET allow students to visualize invisible processes (e.g., chemical bonding, physics principles), resulting in deeper conceptual clarity and improved problem-solving abilities. Studies demonstrate that interactive simulations make science classes more dynamic and participatory. At the same time, the review highlights three recurring barriers: inadequate teacher training, limited digital infrastructure, and slow curriculum integration. Faculty preparedness remains a decisive factor; without proper training, educators often underutilize or misapply simulations (Bhaskar et al., 2023). Moreover, rural and resource-constrained institutions still lack reliable infrastructure, restricting the scalability of SBL. While national initiatives such as NEP 2020 and RMSA 2009 promote technology integration, gaps remain between policy design and practical implementation.

Overall, the findings suggest that interactive simulations significantly improve conceptual understanding, foster critical thinking, and enhance classroom engagement but their full impact depends on strengthening faculty preparedness, infrastructure and curricular reforms.

Discussion

This systematic review scrutinized the role of interactive computer simulations in enhancing science education and classroom engagement in Indian higher education institutions. The evidence collected provides a consistent picture: simulations are powerful pedagogical tools that significantly improve education results, student engagement, and higher-order thinking skills.

Improved Conceptual Understanding and Critical Thinking

The reviewed studies indicates that simulations help students in grasping complex scientific concepts more effectively than traditional lectures. For example, PhET simulations improve comprehension of chemical bonding and physics principles (Mittal, 2022; Sharma & Verma, 2023) by promoting exploration and experimentation. In addition, simulations foster critical thinking and problem-solving skills by allowing students to test hypotheses and visualize outcomes in real time (Mehar & Arora, 2021). The author justified that simulation improved the conceptual understandings and critical thinking.

Enhanced Student Engagement

From the studies we reviewed, simulations stood out as a powerful tool for driving learner engagement. Students were more excited, focused, and active in classrooms that used simulations than in those that employed more traditional pedagogical approaches (Bhaskar et al., 2023). Engagement resulted in peer interaction and collaborative problem solving. This implies that simulations enhance not only the students' capacity to learn in solitude but also the level of communication, interaction, and participation in class. This showed that simulation enhanced student engagement.

Challenges to Implementation

Lack of adequate teacher training came up most frequently, with many teachers not prepared to integrate simulations into their teaching (Bhaskar et al., 2023). This also goes for the absence of adequate digital infrastructure, particularly in rural and poorly funded schools. Further, inflexible curricula and outdated evaluation techniques scaffold the incorporation of simulation-based teaching and learning approaches. It has been justified that inadequacy of resources became hurdle in implementations of technology.

Policy Support and Future Directions

NEP 2020 and Digital India give policymakers a solid starting point for blending technology into classroom instruction. More investment into teacher development, technology, and curriculum will help to align in practices with these strategic initiatives. The authors emphasize that simulations activities move beyond 'teaching aids' and constitute new forms of pedagogy that resonate with the directions of science education around the world. They integrate theory and practice, provide equity of access to expensive physical science laboratories and prepare learners for real-world problem-solving. Interactive simulations have span various disciplines, including computer science and chemistry (Ramanathan et al, 2022; Asadi et al, 2024). The authors strongly believe that with the appropriate legislative frameworks and financial resources, SBL will greatly improve the quality of science teaching and provide every learner in India a greater chance of success.

Limitations

1. **Restricted Study Scope**: This review is limited to studies conducted in India from 2020 to 2024, which may exclude relevant research from earlier years or other countries with similar learning environments.
2. **Differences in Research Approaches**: The studies reviewed use varied methodologies, such as qualitative, quantitative, and mixed methods. These differences make it difficult to directly compare findings or draw universally applicable conclusions.
3. **Infrastructure and Technology Gaps**: Many institutions, particularly those in rural areas, lack adequate digital infrastructure, reliable internet access, and sufficient technological resources.
4. **Teacher Readiness and Training:** Successful adoption of simulation-based learning depends on teachers' ability to integrate these tools effectively.
5. **Challenges in Curriculum Integration**: Interactive simulations are not integrated easily into the curriculum, despite their advantages.

Conclusion

Based on the reviewed research, interactive computer simulations have a profoundly positive impact on science education. It enhances problem-solving skills, fosters critical thinking, and deepens comprehension of the subject. Resources such as PhET demonstrate how simulations give students the opportunity to make their studies more engaging. Furthermore, simulation-based learning settings encourage involvement and teamwork which contributes to a more interesting classroom (Mehar & Arora, 2021). Penitently, the literature points to serious barriers to wider adoption. Excessively rigid curricula, inadequate digital infrastructure and inadequate teacher preparation continue to hinder development (Bhaskar et al., 2023). These difficulties essentially keep simulation-based learning (SBL) from realizing its full potential. While prior initiatives like RMSA 2009 have also highlighted the need for better ICT integration, the country has a lot of potential because to policies like NEP 2020 and initiatives like Digital India. These are more noticeable in rural, underdeveloped and resource-constrained places, but they are still not available at the institutional level. By adding interaction, simulation exercises transcend conventional teaching aids and become tools that have the potential to drastically change science education in India. By filling in the cracks and providing affordable substitutes for actual labs, these simulations can promote 21st-century skills and guarantee equal and significant learning experiences. Their influence may extend to enhancing teachers, fortifying digital infrastructure, or even redefining simulation as the main emphasis of instruction in higher education in order to make it more approachable. By taking these actions, SBL innovation can become more than just a slogan and be embraced as the main approach to providing creative, engaging, and future-proof scientific teaching.

References

- Aldrich, C. (2005). *Learning by doing: A comprehensive guide to simulations, computer games, and pedagogy in e-learning and other educational experiences.* Wiley.
- Asadi, M., Gupta, P., & Roy, K. (2024). The role of SBL in networking education: A case study. *Journal of Computer Science Education, 18(1),* 12–27.
- Asadi, N., Shamsuddin, S., & Singh, V. (2024). Application of simulation-based learning in computer and networking education: Evidence from India. *International Journal of Computer Science Education, 22(1),* 34–50.
- Bhaskar, R., Gupta, A., & Kumar, P. (2023). Challenges and opportunities in adopting simulation-based learning in Indian higher education institutions. *Journal of Educational Technology Development, 35(1),* 64–78.
- Bhaskar, R., Sharma, V., & Singh, A. (2023). Simulation-based learning: Challenges and opportunities in Indian higher education. *International Journal of Educational Technology, 15(3),* 45–59.
- CABE Committee. (2005). *The importance of laboratory-based education in rural areas.* Ministry of Human Resource Development, Government of India.
- Chauhan, V., & Rajput, M. (2020). Virtual learning and simulations in teaching chemical reactions in Indian schools. *Journal of Science Education and Virtual Learning, 14(3),* 88–101.
- De Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations. *Journal of Educational Research, 68(2),* 179–201.
- Government of India (2009). *Rashtriya Madhyamik Shiksha Abhiyan (RMSA): Guidelines for implementation.* Ministry of Human Resource Development.
- Hasyim, F., Prastowo, T., & Jatmiko, B. (2020). The use of Android-based PhET simulation as an effort to improve students' critical thinking skills during the COVID-19 pandemic. *International Association of Online Engineering.* Retrieved from https://www.learntechlib.org/p/218400/

- Joshi, A., & Singh, A. (2020). Bridging the gap between theory and practice through interactive simulations in science education. *Indian Journal of Educational Technology, 22(1),* 33–47.
- Kothari Commission (1966). *Report of the Education Commission on Education and Research 1964-66.* Government of India.
- Kumar, D. (2019). Programs and policies in science education: An overview. *International Educational Applied Scientific Research Journal (IEASRJ), 4(12),* 7–9.
- Kumar, S., & Desai, P. (2022). Enhancing classroom engagement through interactive simulations in science education. *Journal of Higher Education Research, 17(4),* 99–112.
- Makransky, G., & Petersen, G. B. (2021). The cognitive affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality. *Educational Psychology Review, 33*, 937–958.
- Meena, K., & Kumar, D. (2024). Exploring the impact of interactive simulations on student engagement in online science education. *Asian Journal of Educational Technology, 12(1),* 47–59.
- Mehar, R., & Arora, N. (2021). Integrating simulation-based pedagogies to enhance learning outcomes. *Cosmos: An International Journal of Art and Higher Education, 10(2),* 31–35.
- Mittal, A. (2021a). *Sustainability in simulation-based learning: Opportunities in higher education. Journal of Educational Innovation and Technology, 9(3),* 34–49.
- Mittal, A. (2021b). *Interactive learning through SBL: Applications in ICT-driven fields. International Journal of Science Education and Technology, 11(4),* 112–126.
- Mittal, S. (2021a). Interactive simulations in science education: An Indian perspective. *Journal of Science Education and Technology, 28(4),* 1012–1025.
- *CABE Committee Report on universalizing science education.* Ministry of Human Resource Development (2005), Government of India.
- *Rastriya Madhyamik Shiksha Abhiyan (RMSA) framework (2009).* Ministry of Human Resource Development, Government of India.
- National Curriculum Framework. (2005). *A framework for science education reform.* National Council of Educational Research and Training (NCERT), New Delhi.
- National Science Foundation of India. (2019). *Science education policies and implementation strategies.* Retrieved from https://nsf.gov.in
- *National Education Policy 2020.* Ministry of Education, Government of India.
- Panel on Science Education (1964). *Recommendations for laboratory standardization and practical evaluations.* Ministry of Education, Government of India.
- Patel, D., & Mehta, J. (2023). Integrating interactive simulations into undergraduate science curricula. *Journal of Indian Science Education Review, 7(1),* 23–40.

- Rahayu, C. D., & Sartika, S. B. (2020). Students' learning motivation and concepts understanding of science through the use of PhET interactive simulations. *Science Education Journal, 4(1),* 63–79.
- Ramanathan, S., Shanmugam, K., & Subramanian, R. (2022). The role of interactive simulations in enhancing conceptual understanding of chemical bonding in Indian higher education. *International Journal of Educational Technology, 15(3),* 45–60.
- Rao, K., & Gupta, M. (2022). ICT-driven approaches in STEM education: A review. *Educational Research and Reviews, 17(5),* 156–167.
- Ravi, V., & Iyer, K. (2022). Simulation-based approaches for enhancing student engagement in STEM education: A case study from Indian universities. *Journal of Science and Technology Education, 19(3),* 45–60.
- Sharma, N., & Kapoor, P. (2023). Analyzing the effectiveness of simulation-based learning in enhancing conceptual understanding of physics. *Journal of Physics Education Research, 25(4),* 115–130.
- Sharma, N., & Verma, P. (2020). Addressing conceptual challenges in science education through technology. *Advances in Science and Technology Education, 8(2),* 89–104.
- Singh, D., & Yadav, S. (2021). Overcoming conceptual barriers in science learning through interactive simulations: A study in Indian universities. *Science Education Review, 20(3),* 101–115.
- Singh, T., & Kumar, R. (2022). The effectiveness of ICT tools in science classrooms in Indian universities. *International Journal of Pedagogy and Development, 14(2),* 58–72.
- University of Colorado Boulder (2021). *Physics Education Technology (PhET) interactive simulations.* Retrieved from https://phet.colorado.edu
- Verma, T., & Soni, A. (2021). The role of simulations in making complex scientific concepts accessible: Insights from Indian higher education. *Journal of Innovative Learning Technologies, 23(1),* 99–112.
- Wieman, C., Adams, W. K., & Perkins, K. (2008). PhET: Simulations that enhance learning. *Science, 322(5902),* 682–683.
- Kumari, B., & Kumar, P. (2021). Social media: A Web 2.0 technology and a competitive tool for educational development in India. *International Research Journal, Specific Issues,* 11(2), July 2021.