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NEXT-GEN PHYSICS EDUCATION: AR/VR-POWERED SIMPLE PENDULUM LEARNING FOR OBE AND NEP 2020

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SUMMARY

The rapid advancement of immersive technologies has opened new possibilities for enhancing physics education through virtual learning environments. This study presents the design, implementation, and evaluation of an AR/VR-based Simple Pendulum virtual laboratory developed using the Unity platform to support Outcome-Based Education (OBE) under the NEP 2020 framework. The experimental dataset comprised interaction and assessment data from 100 undergraduate students representing diverse academic backgrounds. The effectiveness of learning was measured through pre- and post-test assessments, as well as the analysis of Program Outcome (PO) achievement in cognitive, psychomotor, and affective areas. The findings show a marked positive impact on learning outcomes of students through VR intervention, where the percentage of conceptual understanding, skill development, and engagement and motivation improved from 62% to 80% (+18%), 55% to 78% (+23%), and 58% to 82% (+24%), respectively. The scores of PO achievement also showed a marked improvement, where PO1 (Conceptual Knowledge) improved from 2.2 to 2.8, PO2 (Skill Application) achieved the highest score of 3.0, and PO3 (Innovation and Problem Solving) showed an improvement of 0.7 points on a 3-point scale. The virtual pendulum experiment resulted in an average value of gravitational acceleration of 9.85 m/s^2, which is in close agreement with the standard value, thus confirming the instructional correctness of the simulation. The results clearly show that AR/VR-based virtual laboratories have a significant positive impact on learning effectiveness, digital literacy, and outcome achievement, thus justifying their adoption in modern physics education.

Key words: *augmented reality, virtual reality, physics education, simple pendulum, outcome-based education, NEP 2020, virtual laboratories.*

INTRODUCTION

A computer-based technology known as virtual reality offers tactile, auditory, and visual inputs of a real-time virtual environment [1]. Thus, this technology's application was justified mainly due to its advantages for military use—Virtual Reality simulators make it possible to test various scenarios without exposing costly equipment and personnel to danger. Its value as an educational tool was not the primary consideration. Initially, Virtual Reality technology was linked to scientific military visualization and entertainment for cost reasons. These challenges find effective solutions through robust implementations of deep learning. Achieving cutting-edge results in such applications necessitates the training of deep convolutional neural networks on large datasets [2]. The findings indicated that student collaboration within the AR group demonstrated greater levels of success. In contrast to students who utilized a GPS mapping program, those employing the AR application were able to create a shared platform, which facilitated effective collaboration among team members and the development of common interpretations [3].

The alignment of the real and virtual views or content is such that a user perceives the whole as real. Augmented reality is different from virtual reality in that virtual reality replaces the entire real-world environment with a virtual one [4]. From a psychological standpoint, some authors define Virtual Reality not as a technology but as a mental state that can capture users' awareness akin to actual environments [5].

The remainder of this paper is organized as follows: Section 2 reviews recent AR/VR-based educational studies with critical inference. Section 3 presents the system architecture and pedagogical framework. Section 4 discusses experimental evaluation and results. Section 5 presents a comparative evaluation of the proposed model with existing state-of-the-art techniques to assess its effectiveness. Finally, Section 6 concludes the study and outlines future research directions.

Review of Existing Research

Such an application has been found effective for the practical learning of civil engineering students, equipping them with independent configurations for laboratory experiments, hence minimizing their need for laboratory assistants [6]. An independent application of the gamified virtual laboratory may be argued to result in diminished interactive learning opportunities for civil engineering students, which can have negative impacts on teamwork and associational learning among students and between students and their tutors in physical learning and laboratory settings. This consideration again underscores the significance of effective learning technologies in balancing independent learning applications with learning collaborations for enhanced student outcomes. Augmented reality and other virtual reality technologies have been developed for the creation of independent digital learning settings that surpass traditional classroom learning settings [7]. These digital learning technologies have been found effective for bridging gaps in the learning and application of theoretical and physical knowledge, equipping learners with independent learning interactions for the understanding of physical phenomena, which can be difficult to achieve practically through conventional academic teaching methodologies for different academic disciplines. The introduction of augmented reality technologies and virtual reality has been associated with improved preparedness of students to participate effectively within professional fields. Through the engagement of these technologies, students are able to acquire appropriate skills, problem-solving skills, and experiences within specific disciplines, thus enhancing their preparedness for specific employment positions in the real world [8]. However, based on an analysis of the research conducted to date, most of these studies have been conducted to identify learner engagement levels and have heavily relied on the perceived ease of use of virtual reality technologies, rather than analyzing their specific outcome measures based on academic requirements. According to an analysis of the research conducted to date, there are three major gaps in the analysis procedures. Firstly, there is a lack of outcome-based analysis frameworks which are able to quantitatively measure learner outcomes in the cognitive, psychomotor, and effective skill domains within virtual reality laboratory environments. Secondly, most studies conducted to date have not integrated virtual reality experimentation with outcome-based education frameworks [9]. Third, there was limited availability of scholarly research to support the implementation of immersive virtual reality laboratories as a way to enforce national education policy goals, particularly in the field of physics education in the context of the 2020 National Education Policy in India. To address the issues raised above, the present study aims to promote the creation of a virtual laboratory based on the concept of the simple pendulum, which incorporates the concepts of immersion technology, the manipulation of key factors, and the outcome results of the experiment. The proposed virtual laboratory is based on the concept of outcome-based education, particularly the proposed framework for the 2020 National Education Policy in India. Unlike previous studies, the present scholar focuses on a policy-based approach, as opposed to the more popular engage-based approach, to ensure the proposed virtual laboratory acts as a model for implementation in the field of physics education using the paradigm of virtual reality.

Theoretical background

The experimental assessment was carried out with 100 participants, allowing for a quantitative comparison of learning outcomes before and after the AR/VR treatment. a total of N = 100 participants were used in the experimental assessment. The participants included undergraduate physics students who were exposed to traditional learning and AR/VR-based Simple Pendulum learning modules. Pre- and post-learning assessments were carried out to provide a quantitative assessment of learning outcomes and effectiveness. In this way, individuals can confront their fears, learn to relax and control their emotions in a safe environment [10]. Science education has traditionally utilized laboratory experiments for their conceptual clarity and skill-building. However, physical laboratory access is often limited by resource constraints, location, and the high costs of maintenance. The COVID-19 pandemic has further emphasized the need for remote, technology-enabled alternatives to ensure continued learning [11].

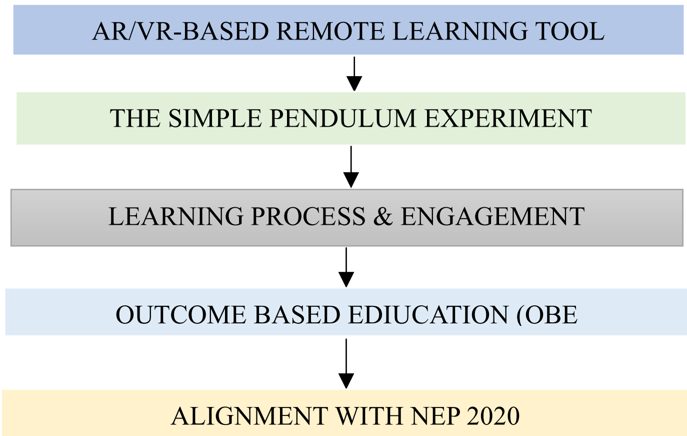

Figure 1. Conceptual block diagram of AR/VR-enabled simple pendulum learning for OBE and NEP 2020

Augmented reality serves as a medium where information is superimposed onto the physical world in alignment with it Figure 1. User-adjustable parameters such as string length, bob mass, initial angular displacement, and damping coefficient allow learners to explore both ideal and non-ideal oscillatory motion within the same experimental framework in (1).

$$T = 2\pi\sqrt{L / g} \quad (1)$$

The Simple Pendulum in the virtual laboratory is modelled as a parameterized dynamic system to allow real-time manipulation and observation of oscillatory behaviour. The pendulum motion is governed by the second-order nonlinear differential equation in (2).

$$\frac{d^2\theta(t)}{dt^2} + \frac{g}{L} \sin\theta(t) = 0 \quad (2)$$

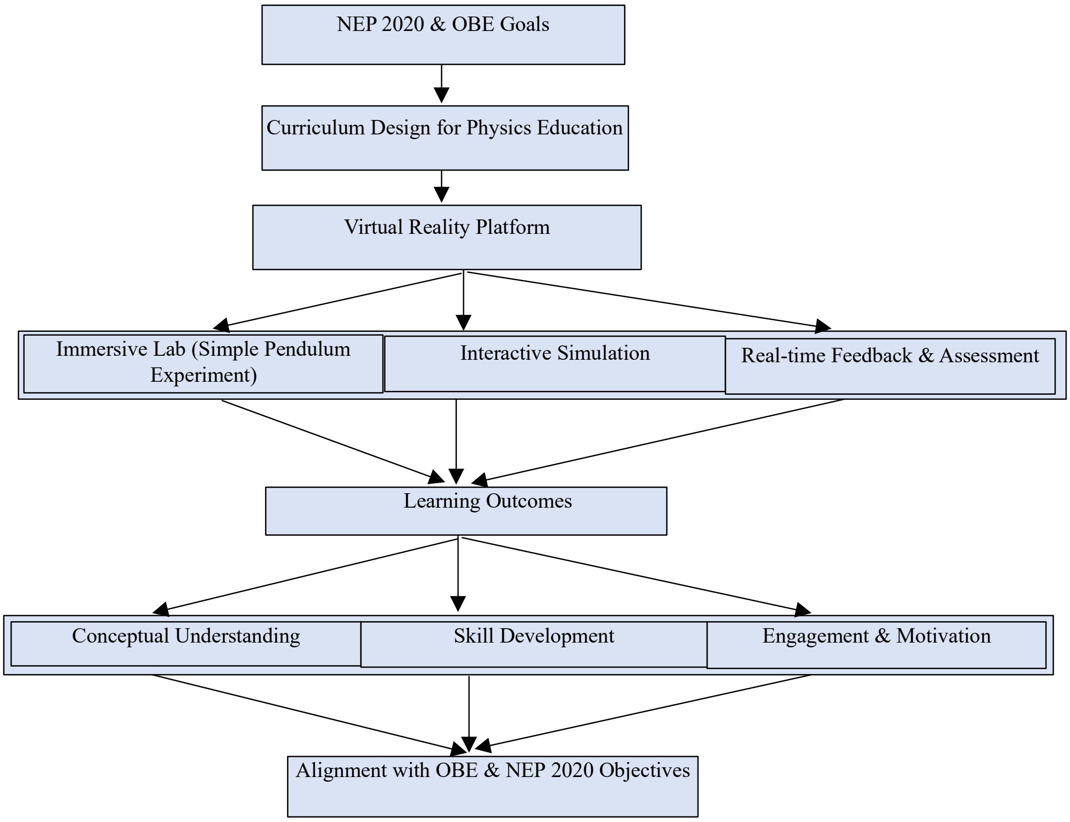

Figure 2. Conceptual framework linking NEP 2020 and outcome-based education with an AR/VR-enabled physics learning model

where θ(t) represents the angular displacement, L is the pendulum length, and g denotes gravitational acceleration. For small-angle oscillations, the system is approximated using the linearized form $sin\ \theta \approx \theta$, yielding a closed-form solution with time period $T = 2\pi\sqrt{L\ /\ g}$ is given in (3).

$$\frac{d^2\theta(t)}{dt^2} + \frac{c}{mL^2}\frac{d\theta(t)}{dt} + \frac{g}{L}\ sin\ \theta(t) = 0 \qquad (3)$$

For small angular displacements (θ<15∘), the model is linearized using $sin\ \theta \approx \theta$, yielding a simplified harmonic motion with time period $T = 2\pi\sqrt{L\ /\ g}$, which is used for estimating gravitational acceleration in (4).

$$g = \frac{4\,\pi^2\,L}{T^2} \qquad (4)$$

where L denotes the effective length of the pendulum and T represents the measured time period of oscillation obtained from the VR simulation [12].

Considering this, we figured it would be best to offer you a comprehensive AR guide that covers augmented reality, its applications, AR examples, and various other related topics. Our AR guide brings together years of experience in the augmented reality field. We have experienced directly the transformation of various industries by augmented reality, and you can anticipate seeing much more AR [13]. While each method has its drawbacks, they are all beneficial. In micro physics and chemistry education, concepts like atoms and their particles (such as electrons, protons, and neutrons), as well as atomic and molecular orbitals, cannot be sufficiently represented by charts, drawings, or models. Virtual reality can nearly eliminate this limitation, facilitating students' understanding of these concepts [14]. In addition, it is necessary to offer citizens life-long education and to endorse a flexible work environment. The VR (virtual reality) technology is often suggested as a significant technological progress that could aid this kind of education.

Figure 2 illustrates the proposed analytical framework that integrates NEP 2020 and OBE objectives into physics curriculum design through an AR/VR-based virtual reality platform. The framework illustrates how immersive lab activities (Simple Pendulum Experiment), simulations, and feedback tools are collectively responsible for improving learning outcomes. The learning outcomes are systematically linked to learning concepts, skill mastery, and engagement, thus forming a systematic approach to assess the effectiveness of instruction. The framework emphasizes the alignment of immersive digital learning with educational outcomes and thus forms the basis for analyzing learning gains and Program Outcome (PO) achievement in the proposed study. [15][16][17]. New experts in fields including biology, chemistry, physics, agriculture, climate science, and social science will be needed for this. Collaborative research on the control of infectious illnesses and vaccine development is crucial due to the increasing frequency of epidemics and pandemics, and the resulting societal difficulties make multidisciplinary education even more important [18].

National Education Policy (NEP 2020)

In the context of science education, NEP 2020 supports innovative instructional models that enable hands-on experimentation, critical thinking, and interdisciplinary learning, thereby preparing students for a knowledge-driven and technology-enabled society in (5) and (6).

$$\text{NEP}_{score} = \alpha C + \beta P + \gamma A \qquad (5)$$

$$\text{NEP}_{Index} = \sum_{i=1}^{n} w_i \times D_i \qquad (6)$$

where D_i represents normalized achievement levels across key learning dimensions—cognitive understanding, practical skills, ethical values, digital literacy, and lifelong learning competencies—and w_i denotes policy-aligned weighting coefficients such that $\sum w_i$=1 in (7).

$$\text{NEP}_{\text{Composite}} = \frac{1}{M} \sum_{k=1}^{M} \left(\sum_{i=1}^{n} w_i \times D_{ik} \right) \qquad (7)$$

where D_{ik} denotes the normalized attainment of the i^{th} learning dimension—such as cognitive mastery, psychomotor proficiency, ethical and social responsibility, digital literacy, and critical thinking—by the k^{th} learner, w_i represents policy-driven weight factors satisfying $\sum w_i$=1, n is the number of learning dimensions, and M is the total number of learners.

Outcome-Based Education (OBE)

OBE is an educational approach that focuses on defining and achieving specific learning outcomes, which students are expected to demonstrate upon completing a course or program, guiding curriculum and instructional decisions [19].

Learning Taxonomies: OBE taxonomies, such as Bloom's and Anderson and Krathwohl's Revised Taxonomy, offer frameworks for classifying learning outcomes across cognitive, affective, and psychomotor domains. This allows students to successfully meet those outcomes. To compute the overall OBE attainment score, a weighted aggregation of individual learning outcome scores is employed, as expressed in Equation (8):

$$\text{OBE}_{att} = \sum_{i=1}^{n} w_i \times S_i \qquad (8)$$

where S_i represents the normalized student performance score for the i^{th} learning outcome, w_i denotes the corresponding weight assigned based on its importance (cognitive, psychomotor, or affective domain), and n is the total number of assessed outcomes.

At the program level, the attainment is calculated by averaging individual student attainments, as defined in Equation (9) AND (10):

$$PO_j = \frac{1}{M}\sum_{k=1}^{M} A_{jk} \qquad (9)$$

$$A_{jk} = \sum_{i=1}^{n} w_i \times S_{\mathbf{ijk}} \qquad (10)$$

where PO_j represents the attainment level of the j^{th} program outcome, A_{jk} denotes the attainment of the j^{th} outcome by the k^{th} student, $S_{\mathbf{ijk}}$ is the normalized score of the k^{th} student for the i^{th} assessment component (such as quizzes, virtual experiments, or lab reports), w_i is the corresponding weight assigned to each component, n is the total number of assessment components, and M is the number of students.

By superimposing digital models over actual experiments, augmented reality applications improve learning and assist students in making the connection between theory and practice. When combined, VR and AR technologies enhance learner engagement and foster deeper conceptual understanding [20].

RESULT AND DISCUSSION

The experimental dataset included interaction and assessment data of students, which were collected during the execution of the AR/VR-based Simple Pendulum virtual lab. A total of 100 students took part in the experiment, which included students with varied academic backgrounds and learning settings. The students took part in multiple structured learning sessions, such as orientation, virtual lab experiment, data collection, and outcome-based assessment. To assess the effectiveness of learning, pre-assessment tests were carried out before introducing the students to the virtual lab, while post-assessment tests were carried out after the completion of the learning sessions. Moreover, the levels of attainment of Program Outcome (PO) were calculated based on the performance of students in cognitive, psychomotor, and affective tasks, using standardized rubrics that are aligned with the criteria of Outcome-Based Education (OBE). The experimental dataset allowed for a comprehensive comparison of the before and after the execution of the VR-based intervention and facilitating the quantitative assessment of the proposed learning framework.

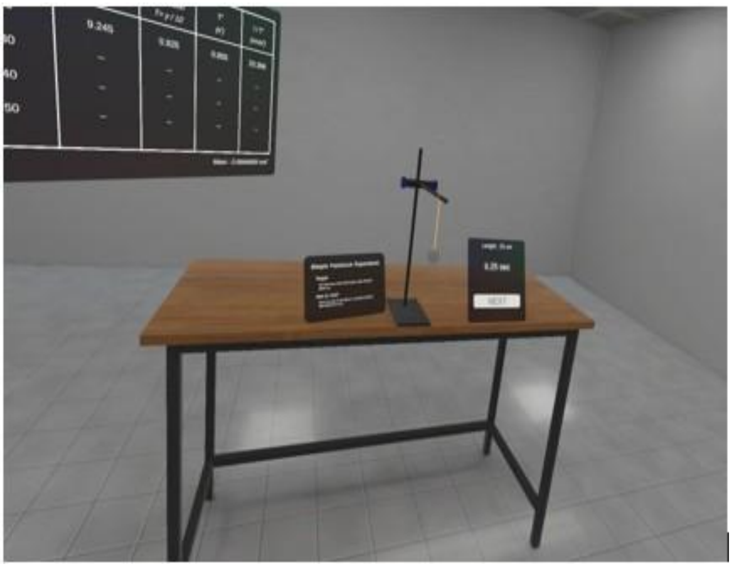

Figure 3. Virtual simple pendulum experiment for determination of gravitational acceleration

Figure 3 shows a pendulum setup with a timer records 9.25 seconds for 10 oscillations at a length of 20 cm. The objective is to calculate gravitational acceleration (g) using T=$2\pi L/g$. A data table on the board shows recorded values, with a mean g value of 9.8549865 m/s². This setup simulates a classic pendulum experiment to determine g.

Figure 4. Interactive data acquisition interface in the virtual simple pendulum experiment

Figure 4 shows a Simple Pendulum Experiment in a virtual lab. The pendulum (length: 20 cm) is swinging, with a digital timer recording 4.59 seconds for a few oscillations. The goal is to determine gravitational acceleration (g) using the pendulum's time period. The data table in the background is currently empty, indicating that new readings are being taken and have not yet been recorded. The buttons labeled STOP and SUBMIT suggest the user is mid-experiment and about to save this trial's result.

Figure 5. Real-time simulation of simple pendulum motion with variable length

Figure 5 captures a virtual lab scene during a Simple Pendulum Experiment where the pendulum has a length of 30 cm and is in motion. The interface is reflecting options to STOP or SUBMIT the result, which is presumably under process.

Figure 6 is depicting the Unity editor interface where the Reflection Probe component is chosen and shown in the Inspector window. The options in the Inspector window are used to control the environment capture process by the probe, including the box size, resolution, and culling mask (which objects are reflected). This is a critical part of 3D environments to increase realism by dynamically or statically reflecting the environment, depending on the chosen settings, to make materials such as metal or glass look more realistic.

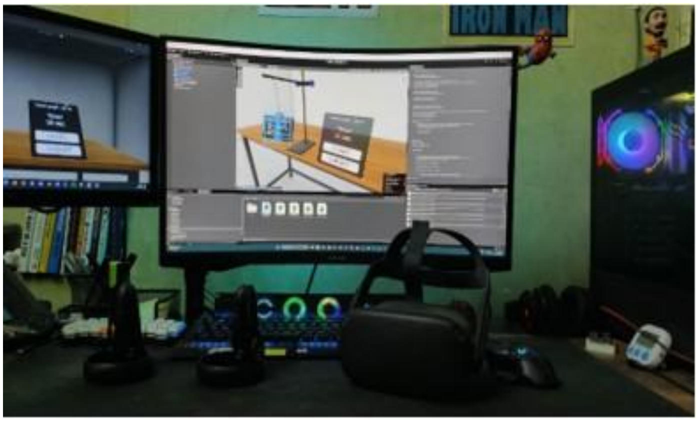

Figure 6. Unity-based VR physics lab development using reflection probes

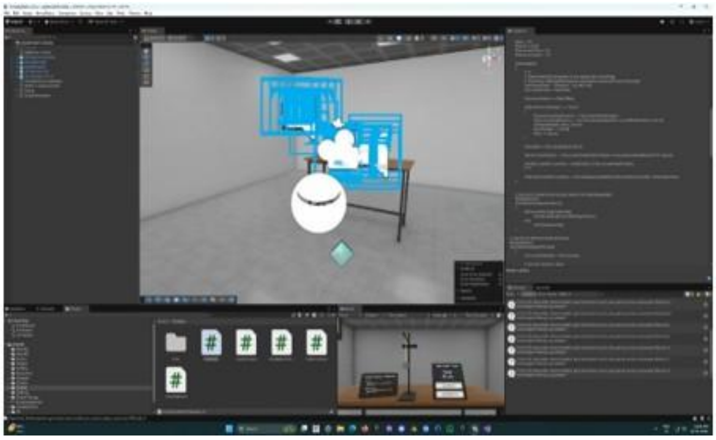

Figure 7. Debugging and navigation mesh visualization in VR science education development

Figure 7 illustrates a 3D scene with debugging or visualization options turned on, specifically the AI Navigation mesh or pathfinding grids, as highlighted by the blue bordered boxes. The console at the bottom right also shows debug messages, which assist the developer in tracking events or errors during runtime. Comparative Illustration of Traditional and VR/AR-Based Simple Pendulum Learning Environments is shown in fig 8.

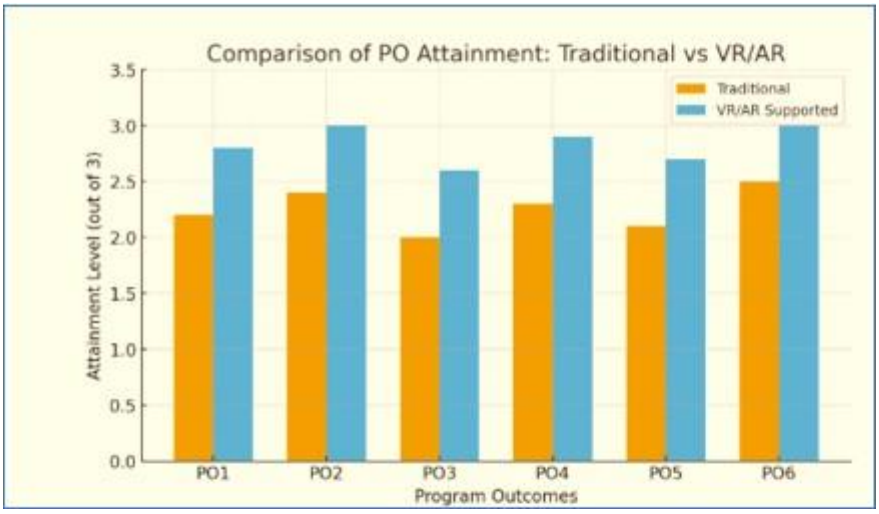

Figure 8. Comparative illustration of traditional and VR/AR-based simple pendulum learning environments

Challenges & Considerations

Figure 9 below shows the quantitative levels of attainment of Program Outcomes (POs) scored on a 3-point OBE scale after the introduction of the AR/VR-enabled Simple Pendulum Virtual Laboratory.

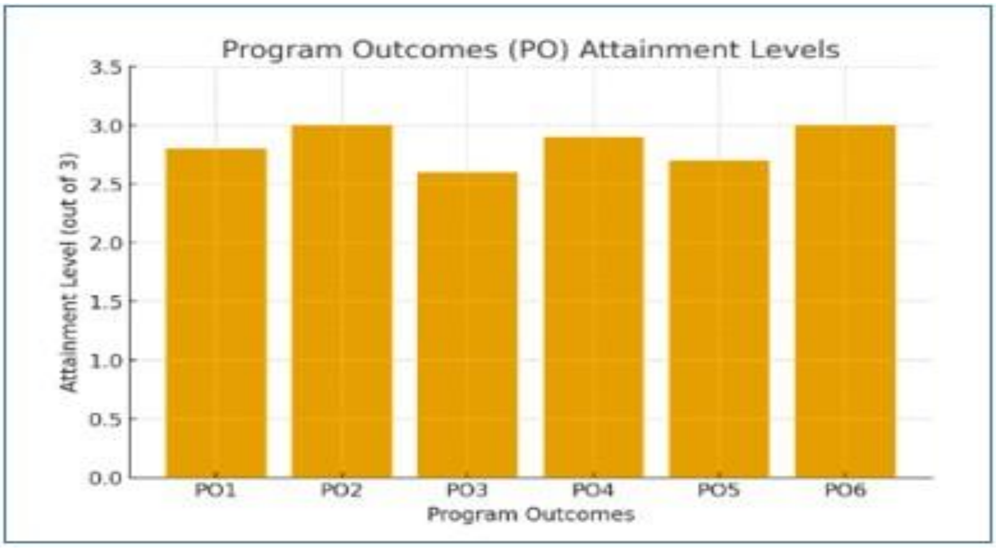

Figure 9. PO attainment levels

The figure shows that there is a high level of attainment of the outcomes, with PO2 (Skill Application) and PO6 achieving a full level of attainment (3.0/3), which indicates that there is a high level of development of experimental and digital skills. This analysis confirms the effectiveness of the virtual laboratory in the achievement of the outcomes in line with the OBE and NEP 2020 goals.

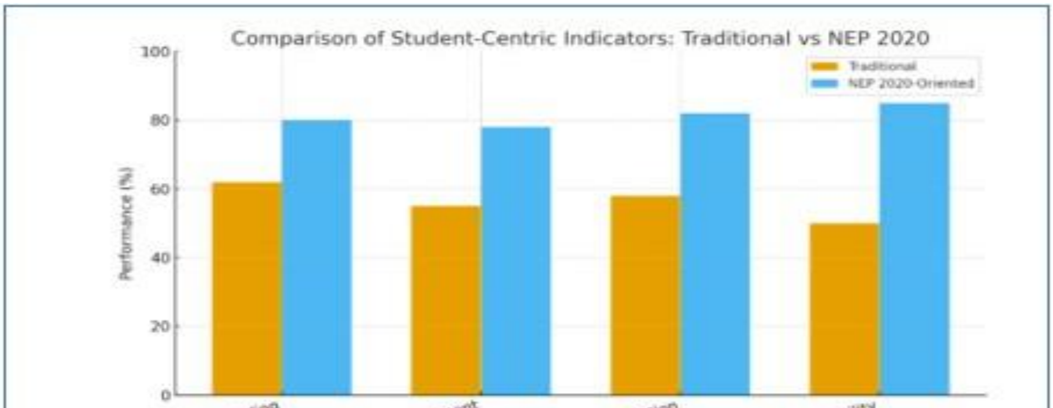

Figure 10. Traditional vs NEP 2020-oriented learning

Figure 10 Comparison of important student-focused performance metrics such as conceptual understanding, skill development, engagement & motivation, and accessibility for traditional teaching practices and NEP 2020-aligned teaching practices using AR/VR technology. This comparative analysis offers critical proof of the marked effectiveness of immersive digital learning pedagogy for students compared to traditional practices.

Table 1 Results drive effective participation of stakeholders, focusing on outcomes rather than input-based processes. Decisions on curriculum, instruction, and assessment aim to achieve outcomes (Table 2). Unlike traditional standardized tests, outcome-based education defines learning by what students can demonstrate.

Table 1. Teacher readiness analysis table

Program Outcome (PO)	Attainment Level (out of 3)	Remarks
PO1: Conceptual Knowledge	2.8	Strong understanding of physics fundamentals enhanced by VR/AR.
PO2: Skill Application	3.0	High competency in applying experimental skills through virtual labs.
PO3: Innovation & Problem Solving	2.7	Improved creativity but needs more integration of research-oriented tasks.
PO4: Ethical & Social Values	2.9	Learners demonstrate responsibility and awareness in digital learning contexts.
PO5: Digital Competence	3.0	Significant improvement in using technology effectively for learning.

Table 2. Combined comparative analysis: traditional vs NEP/OBE framework

Category	Indicator	Traditional (%) / Level	NEP/OBE (%) / Level	Improvement
Student-Centric	Conceptual Understanding	62%	80%	+18%
	Skill Development	55%	78%	+23%
	Engagement & Motivation	58%	82%	+24%
	Accessibility (Remote Learning)	50%	85%	+35%
Teacher-Centric	Digital Literacy	45%	75%	+30%
	Pedagogical Innovation	40%	70%	+30%
	Outcome-Based Assessment	50%	78%	+28%
Program Outcomes (POs)	PO1: Conceptual Knowledge	2.2 / 3	2.8 / 3	+0.6
	PO2: Skill Application	2.4 / 3	3.0 / 3	+0.6
	PO3: Innovation & Problem Solving	2.0 / 3	2.7 / 3	+0.7
	PO4: Ethical & Social Values	2.3 / 3	2.9 / 3	+0.6
	PO5: Digital Competence	2.5 / 3	3.0 / 3	+0.5

The primary focus of necessary reforms to the educational system should be on teachers. Since they genuinely influence the future generation of citizens, it is critical that the new education policy contributes to the restoration of teachers at all levels as the most esteemed and vital members of our society. It must function to empower educators and support them in carrying out their responsibilities as efficiently as feasible.

CONCLUSION

This study demonstrates the effectiveness of an AR/VR-based Simple Pendulum virtual laboratory as an innovative instructional framework aligned with Outcome-Based Education and NEP 2020 objectives. Comparative analysis shows significant improvement in student-focused parameters such as conceptual understanding (18%), skill development (23%), learning engagement (24%), and accessibility for distance learning (35%) compared to conventional teaching methods. Moreover, the value of gravitational acceleration obtained from the virtual experiment was 9.8549 m/s^2, which is highly accurate and emphasizes the authenticity of virtual labs in teaching physics. Though issues associated with infrastructure availability and teacher preparedness still exist, the results clearly indicate that faculty development and effective implementation strategies can overcome these drawbacks. In conclusion, the research work presents concrete quantitative evidence that the use of AR/VR-enabled virtual laboratories improves the quality of learning, enables continuous improvement of outcomes, and empowers teachers, making AR/VR virtual laboratories a feasible and effective solution for future-ready physics education in higher learning institutions. Future research studies should also focus on the cost-effectiveness, energy sustainability, and environmental friendliness of large-scale AR/VR implementations in education.

Finally, longitudinal research studies on knowledge retention, employability skills, and alignment with the changing education policies of NEP 2020 will offer further insights into the transformative power of immersive technologies in STEM education.

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