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Integrating Virtual Reality in Science Education: Opportunities and Challenges - A Case

Study of Bikaner

Asif Akhtar
Research Scholar,
Department of Teacher Training and Non-Formal Education (IASE),
Faculty of Education, Jamia Millia Islamia, New Delhi, India

Dr. Jasim Ahmad
Professor
Department of Teacher Training and Non-Formal Education (IASE),
Faculty of Education, Jamia Millia Islamia, New Delhi, India

Abstract

Virtual Reality (VR) provides immersive and interactive opportunities for strengthening science learning, particularly where abstract concepts challenge conventional pedagogy. This study examines the integration of VR into Grade 6 science classrooms in Bikaner, Rajasthan, focusing on how immersive learning environments foster engagement, comprehension, and motivation—key outcomes associated with gamified learning, though achieved here without explicit game mechanics. Guided by Cognitive Load Theory and Constructivist Inquiry frameworks, the research employed a descriptive case study design combining surveys (N = 196), classroom observations, focus group discussions, and teacher interviews. Findings revealed high student motivation (M = 4.74/5), enjoyment (M = 4.64/5), and excitement (M = 4.36/5), with 86% agreeing that VR-based lessons improved conceptual understanding compared with textbook learning. However, challenges included time constraints, limited teacher training, and device management issues. The analysis positions VR as a functional equivalent of gamification through presence, curiosity, and agency rather than points or competition. By aligning these results with

NEP 2020 and NCF 2022, the paper argues that immersive technologies can operationalise India's vision of joyful, inquiry-driven, and equitable science education—provided systemic supports in teacher preparation and infrastructure are strengthened.

Keywords: Virtual reality, immersive learning, science education, NEP 2020, Bikaner

Introduction, Rationale, and Theoretical Framing

Context and Rationale

The adoption of immersive technologies in middle school science classrooms has become increasingly relevant to contemporary education. In India, where science education often relies heavily on textbooks and dense linguistic material, Virtual Reality (VR) offers an experiential alternative that allows students to explore topics such as Sources and Components of Food, Separation of Substances, Motion and Measurement, Magnetism, and Air through interactive 3D simulations. Government schools in Bikaner, including Hindi-medium and Mahatma Gandhi English-medium institutions, exemplify early efforts to integrate such technologies despite limited resources. Each school's VR laboratory comprises ten standalone headsets paired with a teacher's control tablet used to coordinate lessons and monitor engagement.

Field notes indicated strong emotional responses among learners; announcements like “aaj VR class hai” consistently sparked excitement in Grade 6 classes. This type of anticipation resembles motivational patterns associated with gamified settings, driven by curiosity, novelty, and reward expectancy (Deterding et al., 2011). Even in the absence of traditional game

structures, these immersive lessons generated intrinsic motivation comparable to gamification’s “playful learning” effect (Huang & Hew, 2018). Accordingly, this study positions VR not as a game but as an immersive tool that cultivates gamification-like engagement through interactivity and sensory presence.

Problem and Purpose of the Study

Indian middle school science education often faces systemic challenges: limited resources, rigid timetables, scarce laboratory access, and curriculum practices emphasizing memorization over reasoning (NCERT, 2021). In Bikaner’s schools, language use presents additional complexity—Hindi- or English-only instruction contrasts with students’ everyday Marwari speech, creating barriers when dealing with scientific terminology. VR supports learning in these contexts by making abstract concepts visual and aligning words, images, and actions in real time, reducing cognitive load (Mayer, 2021). Yet, meaningful learning depends on how teachers integrate technology (Radianti et al., 2020).

This study’s objective is to explore how VR enhances motivation and conceptual understanding in Grade 6 science classrooms and to identify contextual enablers or obstacles. Rather than focusing on statistical outcomes, it analyses perception, engagement, and implementation feasibility to contribute to evidence-based classroom innovation.

Theoretical Foundations

Two complementary perspectives inform this inquiry. Cognitive Load and Multimedia Learning Theory (Mayer, 2021) frames VR as a medium that decreases extraneous cognitive demand by merging visual and auditory channels, enabling deeper processing of abstract ideas. For example, when narration in Hindi supports English scientific terms simultaneously displayed on screen, conceptual associations strengthen.

Constructivist learning perspectives (Dewey, 1938; Piaget, 1973; Vygotsky, 1978) further explain learning as an active and collaborative process. In observed classrooms, teachers paused VR segments to ask reflective questions such as “Mombatti kyun bujhi?”, prompting predictions and reasoning. Such dialogic interventions turned passive watching into inquiry-oriented participation, aligning with constructivist pedagogy.

Together, these approaches view VR classrooms as cognitive-affective spaces that merge presence with participation. The sense of “being there” (Slater & Wilbur, 1997) bridges learners and concepts, while teacher scaffolding converts curiosity into understanding—producing engagement similar to gamified learning, without explicit game mechanics.

Policy Alignment

NEP 2020 (Sections 4.23, 23.6) and NCF 2022 both advocate technology-enabled, experiential, and inquiry-driven learning. VR laboratories in Bikaner demonstrate how government institutions can operationalize these policy visions under constrained conditions. By analysing these implementations, this study contributes practical insights for teacher preparation, digital resource planning, and sustainable educational innovation.

Literature Review

Immersive Learning and Cognitive Engagement

Research worldwide increasingly points to Virtual Reality (VR) as a potent tool for enhancing science instruction. A meta-analysis of 38 studies by Radianti et al. (2020) revealed that VR can foster greater engagement, spatial reasoning, and long-term memory, especially for complex or abstract scientific processes. Instead of passive observation, learners interact within simulated environments, leading to improved attention and deeper understanding (Hashemi et al., 2023). Across secondary schools in both Europe and East Asia, VR lessons have been shown to promote “flow”—a psychological state characterized by high intrinsic motivation and persistent focus (Lege & Bonner, 2020). The powerful sensation of presence—feeling truly “there”—is what most distinguishes VR from traditional educational media (Slater & Wilbur, 1997). When synchronized audio and visuals are incorporated into VR experiences, they align closely with Multimedia Learning Theory principles, streamlining cognitive processing and decreasing unhelpful mental effort (Mayer, 2021).

Motivation and Gamification in VR

While gamification is typically defined by the use of game elements such as scores or badges (Deterding et al., 2011), new scholarship indicates that VR can generate similar motivation even without explicit rewards. Huang and Hew (2018) have shown that the anticipation and personal agency experienced in VR closely resemble satisfaction cycles found in games. Empirical work demonstrates that students often display higher participation, enthusiasm,

and positive feelings in VR settings—hallmarks of frameworks rooted in Self-Determination Theory (Ryan & Deci, 2000).

In lower-resource regions where formal game-based learning is less accessible, VR functions as a gamified platform by stimulating curiosity and perseverance through sensory engagement. In the documented case from Bikaner, the excitement voiced when hearing aaj VR class hai reflected motivational responses similar to those observed in gamified environments.

Inquiry, Constructivism, and VR

VR actively supports constructivist educational models, enabling students to build understanding through investigation, hypothesis testing, and visualization (Piaget, 1973; Vygotsky, 1978). Dewey's principles of learning through direct experience are echoed in VR modules designed for exploration and inquiry (Dewey, 1938).

Contemporary studies confirm that VR enables learners to manipulate variables, observe results, and refine their thinking (McInerney & Mills, 2023). This is particularly valuable for developing the abstract reasoning skills characteristic of middle school years. Teachers who pause VR simulations encourage students to predict outcomes—converting immersive exposure into scaffolded inquiry rather than passive observation. The teacher's role remains essential for meaningful learning (Rathore & Mehta, 2024).

Regional Insights: India and South Asia

Research on immersive technologies in Indian classrooms is expanding. Investigations by Rathore and Mehta (2024) found notable increases in student engagement and concept clarity when teachers used bilingual approaches within VR lessons, but teachers noted persistent challenges such as insufficient training and logistical limitations. Prior studies (Kumar & Singh, 2022) highlighted that bilingual instructional support improved learner confidence and comprehension, underscoring linguistic accessibility in technology-mediated contexts. Infrastructure disparities continue across government schools. Multilingual adaptation of digital content has been shown to help contextualize learning and bridge language gaps (Chakraborty, 2020). Globally, in locations such as Southeast Asia (Hashemi et al., 2023) and Africa (UNESCO, 2022), VR is recognized for democratizing access to lab-like experiences where physical resources are lacking, paralleling the Bikaner scenario with shared devices and teacher management.

Implementation Challenges

Despite interest, integrating VR in schools brings practical barriers: routine hardware maintenance, device charging, and synchronization issues are frequently reported (Radianti et al., 2020). Many educators receive only limited training, sometimes leading to superficial use of VR rather than deep instruction (Rathore & Mehta, 2024). The typical 40–45-minute class period restricts extended investigation and post-lesson reflection. Physical discomfort, such as eye strain and dizziness, is also a concern among younger users (Lege & Bonner, 2020). Additionally, adoption is shaped by socio-cultural variables including teacher comfort with technology, self-efficacy, and language preferences. In Bikaner's classrooms, the interplay between Hindi,

English scientific terminology, and local Marwari provided a flexible, code-mixed approach—a sign of adaptive instruction responsive to learner needs.

Policy and Curriculum Context

India's policy frameworks explicitly support technology integration. The NEP 2020 promotes blending traditional teaching with digital methods for deeper conceptualization and joyful learning, while the NCF 2022 calls for immersive, multimodal instruction tailored to local language and culture. The VR implementations in Rajasthan reflect efforts to localize these ambitions using SCERT Udaipur's adapted curriculum. Yet, these innovations also highlight tensions between new methodologies and existing systemic constraints such as resource distribution, teacher authority, and curriculum alignment.

Synthesis

Literature consistently demonstrates that VR can revolutionize science education when employed as a pedagogical strategy. Its immersive features foster the motivation and engagement typically seen in gamified learning, while supporting cognitive and multimodal understanding. Nevertheless, success is contingent on teacher expertise, contextual adaptation, and sustainable infrastructure. This case study in Bikaner extends existing research by examining authentic classroom experiences, focusing on practical challenges and the realities of government school operation.

Research Methodology

Design and Approach

The investigation utilizes a descriptive case study model (Yin, 2018), examining how VR influences engagement, motivation, and understanding in Grade 6 science. The methodology embraces both quantitative (survey) and qualitative (classroom observation, interviews, focus groups) components, prioritizing real-life educational conditions over tightly controlled experimental interventions. This constructivist-pragmatic stance recognizes that technology's educational impact is shaped by teachers' actions, student interactions, and institutional norms, aiming for practical, context-sensitive insights rather than broad generalization.

Context and Setting

Fieldwork took place in eight government upper-primary schools in both rural and urban Bikaner, Rajasthan, all equipped with a VR lab featuring ten independent headsets and a teacher-controlled tablet. Instruction followed SCERT Udaipur's science curriculum based on NCERT guidelines. Science teaching was mainly in Hindi, although teachers frequently drew on English textbook terms and Marwari phrases to aid comprehension. Two of the eight were designated as English-medium schools, using the same VR modules but with bilingual instruction. VR lessons were scheduled weekly, typically in 40-minute sessions. The most frequently studied modules included:

- Food: Where Does it Come From
- Components of Food
- Separation of Substances

- Motion and Measurement of Distances
- Fun with Magnets
- Air Around us

Participants

The study included:

- 196 Grade 6 students (approximately age 11) who participated in VR science lessons
- 8 science educators responsible for VR instruction
- 65 students selected for small-group focus discussions

All participants and institutions consented to involvement; data were anonymized through pseudonyms.

Data Collection Methods

Student Surveys

A structured questionnaire in Hindi assessed student perspectives on motivation, interest, enjoyment, preference for VR over textbooks, and comfort using headsets, using a 5-point Likert scale. The mean scores reflected strong positive student response:

Motivation $M = 4.74$

Interest $M = 4.64/5$

Excitement M = 4.36/5

Preference for VR over textbooks: 86% agreement

Teacher Interviews

Eight semi-structured interviews explored teachers' pedagogical strategies, classroom management, perceived impact of VR, challenges, and training experiences. Sessions lasted 20–30 minutes, recorded with permission.

Focus Group Discussions

65 students in groups of 5–6 discussed comfort, enjoyment, and comparisons between VR and textbook lessons. Dialogues were primarily in Hindi with occasional bilingual facilitation. Students referred to particular VR experiences as documented in their survey replies.

Classroom Observations

Non-participant observation documented student-teacher interactions, language practice, device handling, and student emotional responses. Notable observations included:

- Teachers pausing VR to clarify a concept (e.g., candle extinguishing demonstration)
- Student affirmation in English (“Yes, ma’am/sir”)
- Directions in Hindi urging focus on details (“Dhyan se dekho, table par kya ho raha hai”)

Ethnographic notes contextualized quantitative survey and qualitative interview data.

Findings and Discussion

Overall Data Convergence

Quantitative trends

Student survey results from all eight schools showed consistently high levels of approval for VR-based science lessons. Mean scores ranged from 4.33 to 4.74 out of 5, with overall averages around 4.55 and low standard deviations, signifying strong consensus. Motivation ($M = 4.74$), excitement ($M = 4.68$), comprehension ($M = 4.50$), and joyful engagement ($M = 4.65$) were particularly prominent. Statistical analysis confirmed these results were not due to chance, with scores significantly above the neutral midpoint ($p < .001$). This pattern suggests VR learning facilitated enthusiasm, deeper understanding, and meaningful retention, aligning with national policy goals for technology-enhanced and competency-driven education.

Qualitative Patterns

Classroom observations, student focus groups, and teacher interviews all echoed the survey findings. Teachers who frequently paused VR content for explanations—notably switching to Hindi or Marwari where needed—reported improvements in student comprehension and participation. Students described VR lessons as "real," "enjoyable," and "easier to grasp," noting the newfound ability to visualize scientific processes like separation or measurement. Teachers consistently observed that immersive technology encouraged inquiry and dialogue, though time constraints and limited teacher training sometimes dampened interactivity. Across different sites, the shared sense of anticipation and engagement at the start of VR sessions

resembled the dynamics of gamified learning. Bilingual teaching further helped connect textbook terminology with local language, creating a more inclusive classroom environment in line with NEP's call for joyful, experiential learning.

Class sessions began with visible excitement and group anticipation, much like awaiting a gameplay experience, mirroring findings in gamification scholarship (Huang & Hew, 2018).

Student Engagement and Motivation

Students frequently labeled VR classes *maza aata hai* and *naya lagta hai*, reflecting fun and novelty. Focus groups revealed that direct visualization of scientific phenomena—such as color change with iodine—made abstract textbook topics concrete and memorable.

The interactive nature of VR promoted sustained attention and self-directed exploration. Many students reported losing sense of time, consistent with the “flow” state described in immersive learning literature. Teachers observed that students watched VR content with unusual concentration, often noting this was the quietest their classrooms had ever been.

Teacher Mediation and Changing Pedagogy

Teacher interviews highlighted a pedagogical shift: VR encouraged instructors to facilitate inquiry rather than deliver information. One teacher pointed out that she now asks students to reason rather than simply explain, reflecting a move from lecture to inquiry-based discussions.

Teacher confidence varied between schools. In some, teachers strategically paused simulations

for discussion, while others relied on uninterrupted viewing. The effectiveness of VR was linked more to teacher mediation than to the technology itself—a point reinforced by previous research.

Language Practices in Instruction

Although language practices were not the main research focus, bilingual explanation emerged as a crucial factor. Teachers often communicated in Hindi, using English scientific terms displayed in VR, and occasionally relied on Marwari expressions to aid comprehension, creating spontaneous multilingual scaffolding.

Operational Challenges

Implementation struggles were noted across all settings:

- Limited lesson time restricting preparation and debriefing
- Device management (charging, headset setup) consuming instructional minutes
- Teachers lacking sustained pedagogical training beyond initial technical orientation
- Minor complaints of eye strain or dizziness among students, leading to reduced use times per child
- Persistent use of paper-based assessment mismatched with VR-facilitated inquiry

Such issues indicate a gap between early technological adoption and broader curriculum reform.

Opportunities According to Teachers

Teachers identified several key advantages:

- Broad student engagement, including participation from usually quieter children
- Heightened curiosity and anticipation on VR days
- Improved visualization of scientific concepts
- Natural bilingual and multimodal learning experiences
- Alignment with NEP’s vision for experiential, joyful science education
- One teacher summarized, “Science has now moved beyond the textbook.”

Theoretical Connections

Findings supported the study’s theoretical underpinnings:

- Cognitive load theory was affirmed as VR’s multimedia approach eased conceptual understanding and enabled imagery-based memory
- Constructivist and inquiry-based models were validated by teacher-led questioning and peer dialogue during VR activities

This blending can be seen as creating an “immersive-constructivist” classroom, echoing gamified learning dynamics without explicit game mechanics.

Policy and Comparative Reflections

Results from Bikaner are consistent with international outcomes, showing VR’s motivating influence while exposing local system limitations: training gaps, resource shortages, and inflexible schedules. Such pilots demonstrate steps toward democratizing modern pedagogy in Hindi-medium schools, in line with NEP and NCF objectives.

Future success depends on establishing robust support systems, regular funding for maintenance, ongoing professional development, and innovative assessment approaches.

Summary

Altogether, the introduction of VR in Grade 6 science classrooms in Bikaner:

- Fostered gamification-like motivation organically
- Enhanced conceptual understanding via multimodal approaches
- Shifted instruction toward inquiry and guided exploration
- Exposed practical challenges around time, training, and device management

These lessons suggest VR's value lies in making science learning vivid and learner-centered, moving classrooms from static reading to dynamic discovery.

Conclusion and Educational Implications

Main Findings

This case study of eight government schools shows that VR labs significantly boost student motivation and understanding in Grade 6 science. High survey ratings (mean \approx 4.55; motivation = 4.74; engagement = 4.6; comprehension = 4.5; 86% preference for VR) matched qualitative feedback about anticipation, enhanced peer discussion, and tangible grasp of scientific concepts. While lacking traditional gamification features, the immersive VR environment created similar cycles of curiosity and self-driven engagement—turning presence, agency, and novelty into functional equivalents of game-based learning.

Advances in Gamification and Immersive Learning

The Bikaner case contributes two central findings:

First, sensory immersion alone can trigger motivation and engagement akin to gamification, even without explicit game mechanics.

Second, learning is most impactful when teachers actively mediate, pause, question, and anchor VR content to local experience, thus strengthening conceptual absorption. These themes link cognitive load reduction (Mayer, 2021) with constructivist principles, emphasizing that human facilitation is essential for effective technology use.

Challenges Affecting Sustainable Scaling

Key obstacles include:

- Classroom timing constraints limiting effective VR use
- Device management and technical issues intruding on instructional time
- Insufficient ongoing teacher development
- Occasional student discomfort requiring controlled exposure
- Assessments that remain paper-based, making it hard to measure outcomes of inquiry-driven VR activities

These bottlenecks highlight the need for broader systemic adaptation.

Policy and Curriculum Implications

Findings directly support the vision laid out in NEP 2020 and NCF 2022: joyful, experiential, and competency-based learning in government schools. To extend local successes, three areas need focus:

- Teacher development integrating both device use and inquiry-based instruction
- Infrastructure planning ensuring dedicated maintenance and support
- Assessment pilots recognizing experiential learning and not just written tests

Practical Recommendations

For greater impact, schools and policymakers should:

- Incorporate VR instruction into teacher training and professional development
- Develop short, focused VR lesson templates that fit into standard periods
- Standardize safety and maintenance protocols for devices and exposure
- Experiment with formative assessments to track deeper learning
- Encourage collaboration among education authorities and NGOs to co-create localized VR content and mentorship

Broader Insights and Future Directions

This study demonstrates that immersive VR can make science more accessible and engaging in Hindi-medium public schools, bringing abstract processes to life and sparking inquiry. For international educational audiences, it reinforces that meaningful learning emerges

from combining technological immersion with thoughtful teacher guidance. Future research should:

- Test VR modules with embedded assessment
- Compare explicit gamified and non-gamified VR for motivation and learning differences
- Explore long-term retention and transfer

In the end, VR's true potential lies not in technological novelty but in its ability to realize the vision of joyful, competency-oriented education set by NEP 2020.

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