IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Reimagining Science Education In The 21st Century: A Constructivist And Inclusive Framework For Equitable Learning

Dr. Nibedita Kar
Assistant Professor (Teacher Education)
DPIASE, Berhampur

Mr. Balaram Sahu
M.Ed 2nd Year Student
DPIASE, Berhampur

Abstract

Science education is at a vitalpart as it grapples with the demands of a knowledge-grounded, globalized society. This study investigates the pedagogical, institutional, and policy-related challenges impeding effective science teaching at the secondary level in India. Employing a mixed-methods approach across diverse school settings, the study analyzes teacher practices, student perceptions, and systemic constraints. Results indicate a predominant reliance on didactic teaching methods, limited integration of inquiry-based approaches, and minimal contextualization of scientific content. Female and rural learners face disproportionate barriers to meaningful engagement. The paper advocates a restructured science education model grounded in constructivist pedagogy, culturally responsive curriculum, and robust teacher development. Implications for policy and practice are discussed, aiming to make science education more inclusive, engaging, and socially relevant.

Keywords: science education, constructivism, inquiry-based learning, inclusive pedagogy, STEM, education reform, secondary education

1. Introduction

Science education forms the bedrock of an enlightened, innovative, and sustainable society. In the 21st century, the role of science education transcends traditional content delivery, requiring a shift toward critical thinking, interdisciplinary learning, and real-world problem solving. The ability of learners to navigate complex issues—such as climate change, public health, and technological disruption—depends significantly on how science is taught and internalized.Despite policy frameworks advocating reform, secondary science education in India remains largely rooted in transmission-based pedagogy. The National Education Policy (NEP, 2020) calls for experiential and inquiry-driven learning, yet classroom practices often fall short of this vision due to systemic limitations. This paper aims to critically examine the existing practices and propose a reimagined science education framework that is both equitable and future-ready.

2. Theoretical Framework and Literature Review

Ruggirello and Brockhouse (2024), in their article *"A Framework for Equitable Lesson Development"* in *Science and Children*, present an inclusive instructional framework based on Universal Design for Learning (UDL) principles and constructivist pedagogy. The framework offers practical tools for teachers to create equitable science lessons by incorporating differentiation, formative assessment, and collaborative grouping strategies. Rooted in Vygotsky's Zone of Proximal Development (ZPD), the approach emphasizes supporting diverse learners by meeting them where they are developmentally and culturally. Their model underscores the importance of planning science instruction that is meaningful, relevant, and accessible to all students, especially those from marginalized backgrounds.

King-Sears et al. (2024) reviewed 120 studies demonstrating UDL's success in making science accessible to neurodiverse learners. Key strategies include multimodal content delivery (e.g., videos, tactile models) and flexible assessments (Rappolt-Schlichtmann et al., 2022). Critics note UDL's limited adoption due to rigid standardized testing (Basham et al., 2023).

The meta-synthesis published in *Frontiers in Education* (2023), titled *"Creating an Equitable and Inclusive STEM Classroom,"* explores inclusive teaching practices within STEM higher education. Although authors are not named in the summary, the article integrates findings from various studies using a culturally responsive pedagogy framework. Anchored in Ladson-Billings' theory of culturally relevant teaching and Bronfenbrenner's ecological systems theory, the review identifies classroom climate, instructor cultural competency, and faculty agency as critical factors for promoting equity. The study emphasizes that STEM educators must adopt inclusive practices intentionally, viewing equity not as an add-on, but as a core principle of effective teaching and learning.

Science learning is best understood through the lens of constructivist theory, which posits that knowledge is actively constructed by learners (Bruner, 1961; Vygotsky, 1978). Inquiry-based learning (IBL) operationalizes this theory by engaging students in authentic scientific practices—posing questions, designing investigations, interpreting data, and communicating findings (Harlen, 2015).

Globally, frameworks such as OECD's Education 2030 and UNESCO's Education for Sustainable Development (ESD) advocate for integrating 21st-century competencies—collaboration, systems thinking, digital literacy—into science curricula. However, implementation remains uneven, particularly in resource-constrained contexts.

Lastly, the article *"A Future Trend for Science Education: A Constructivism-Humanism Approach to Trans-Contextualisation"* (2022) in *Education Sciences* offers a theoretical blend of constructivism and humanistic education. The authors propose that science education should transcend classroom boundaries to address societal and global challenges. Rooted in Bruner's constructivist theory and Maslow's humanistic psychology, the paper suggests that students thrive when they connect learning with purpose, meaning, and real-world relevance. The approach encourages teachers to design curricula that foster civic engagement, ethical reasoning, and interdisciplinary understanding—key pillars for preparing responsible, globally conscious citizens.

3. Research Objectives

This study was based on the following research objectives:

1. To assess the current pedagogical practices in secondary-level science classrooms.
2. To explore students' attitudes and challenges in engaging with science subjects.
3. To analyze teacher preparedness and institutional support mechanisms.

4. Methodology

4.1 Research Design

A mixed-methods design was adopted, integrating quantitative survey data with qualitative insights from classroom observations, interviews, and focus group discussions.

4.2 Sampling and Context

The study was conducted in five secondary schools—two urban, two rural, and one tribal—across Odisha, India. A purposive sample of 300 students and 25 science teachers participated.

4.3 Instruments and Data Collection

1. Student Questionnaire: A 20-item Likert-scale instrument measuring interest, perceived relevance, and difficulty of science learning.
2. Classroom Observations: Structured checklists assessed teaching style, student engagement, and resource usage.
3. Teacher Interviews: Semi-structured interviews captured pedagogical approaches, professional development needs, and policy awareness.
4. Focus Groups: Student discussions provided insights into lived experiences, aspirations, and barriers.

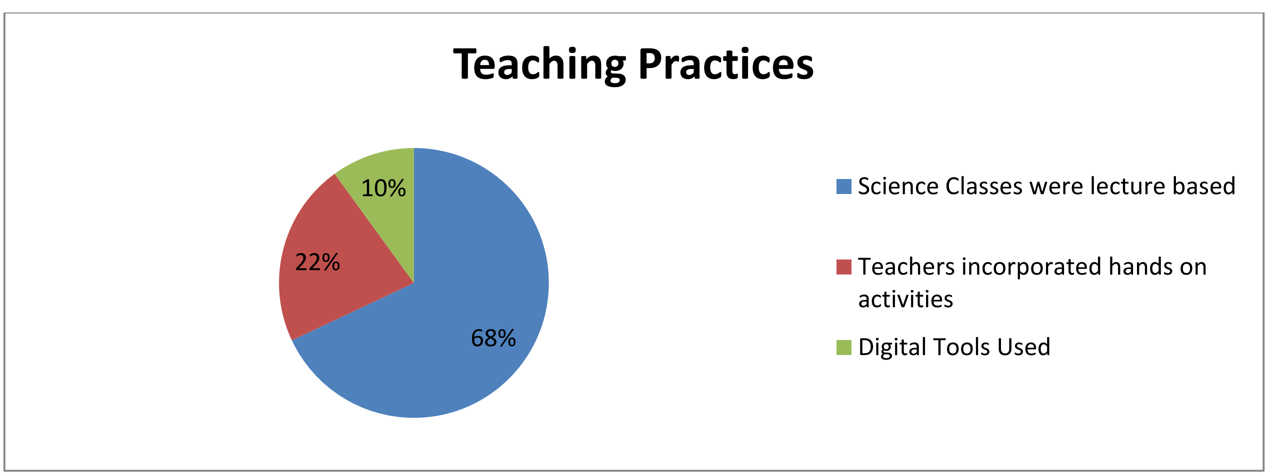
4.4 Data Analysis& Interpretation

Quantitative data were analyzed using SPSS (descriptive statistics and chi-square tests), while qualitative data were thematically coded using NVivo. The study utilized both quantitative and qualitative tools to examine the state of science education in selected secondary schools across Odisha. The key data points are as follows

4.4.1 Teaching Practices in Science Classes

S. No.	Teaching Method	Description	Percentage
1	Lecture-Based Instruction	Classes primarily conducted through lectures	**68%**
2	Hands-On Activities	Teachers incorporated practical, experimental tasks	**22%**
3	Use of Digital Tools	Digital resources such as videos, simulations, or smartboards were used	**10%**

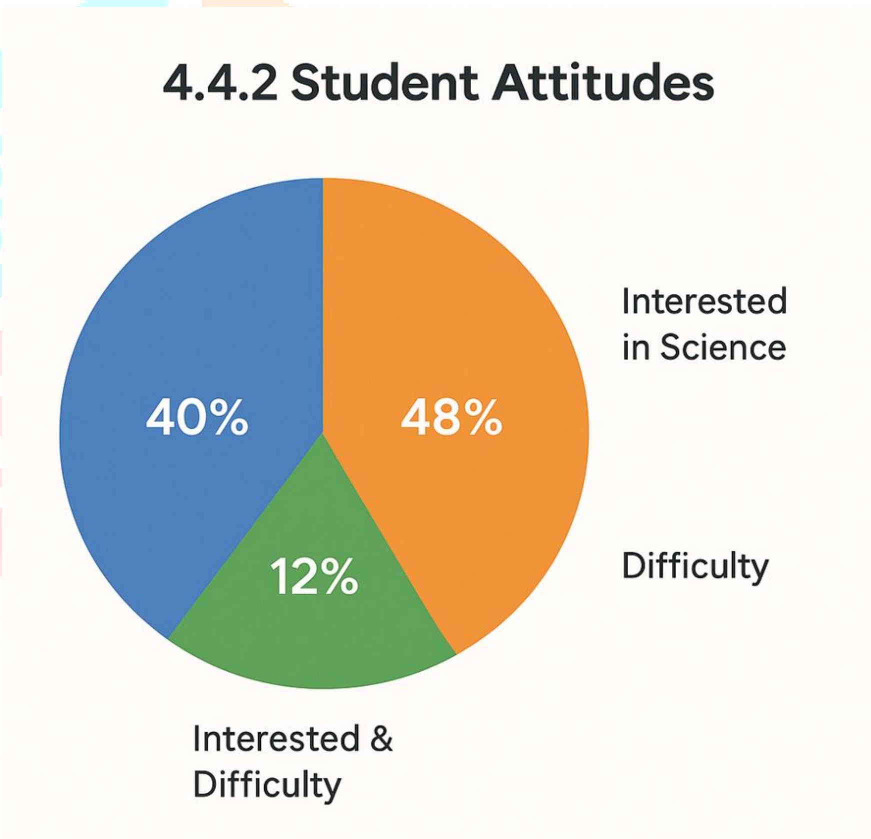
The above table represented in graph below.



- Out of 100%,68% of science classes were primarily lecture-based with minimal student-teacher interaction.
- Out of 100 %, Only **22%** of teachers conducted regular hands-on or laboratory-based sessions.
- Out of 100%,Less than **10%** of classes used digital tools or multimedia, with many citing lack of training or resources.
- Understood! Here's the table with the correct **column order** — **Student Attitude first, then Description**, arranged chronologically:

S.No.	Student Attitude	Description	Percentage (%)
1	Interested in Science	Students Interested in Science only	40
2	Difficulty in Understanding Concepts	Students Facing Difficulty in Understanding only	48
3	Interested & Difficulty	Students Both Interested in Science & Facing Difficulty	12

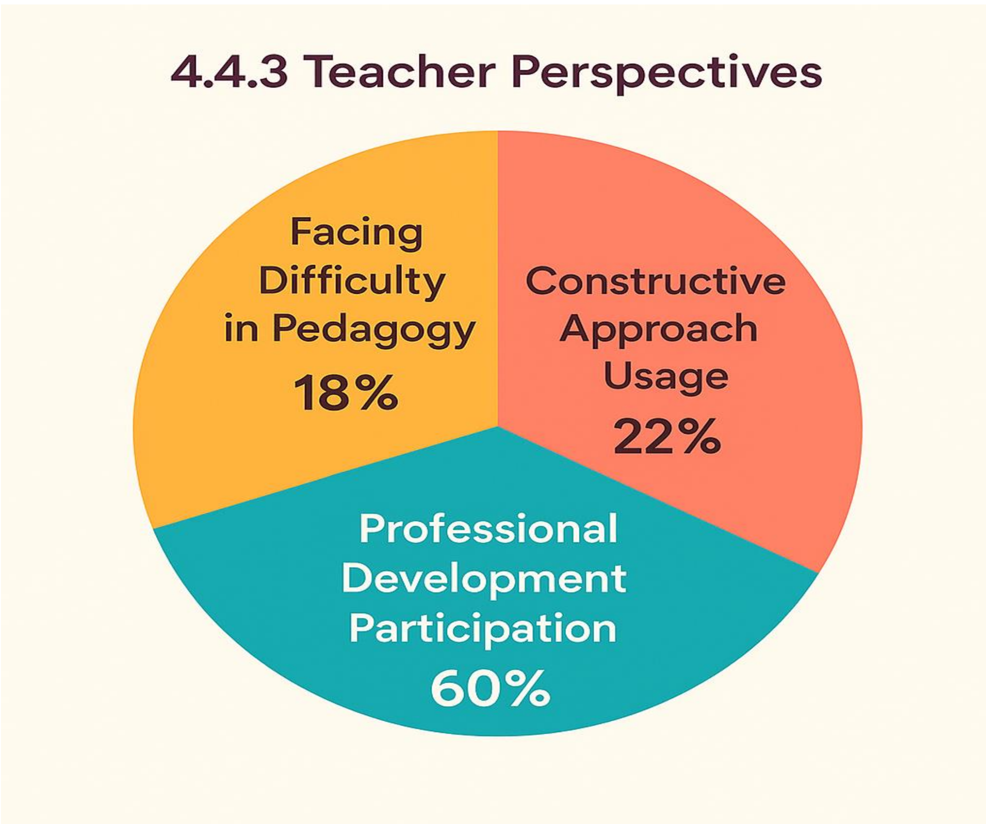
The above table represented diagrammatically in Pie-Chart.



- **Out of 100% students, 72%** of students reported a general interest in science.
- **Out of 100% students, 64%** found it difficult to comprehend textbook concepts.
- Female students expressed lower confidence levels as compared to male students.
- Rural and tribal students highlighted lack of access to enrichment resources and career guidance.

S.No.	Teacher Perspective	Description	Percentage (%)
1	Facing Difficulty in Pedagogy	Teachers facing difficulty in implementing inquiry-based pedagogy	18
2	Professional Development Participation	Teachers who have attended professional development workshops	60
3	Constructive Approach Usage	Teachers using a constructive (student-centered) approach in class	22

The above table represented graphically in the pie-chart.



- Out of 100%,**60%** of teachers indicated discomfort or challenges in implementing inquiry-based pedagogy.
- Out of 100%, Only **18%** had attended any professional development training within the past year.
- Commonly reported barriers included syllabus overload, examination pressures, and lack of institutional support.

4.4.4 Qualitative Insights

- Classroom observations revealed limited student engagement and a lack of differentiated instruction.
- Focus group discussions showed students often found science content disconnected from their daily lives.
- Teachers expressed frustration over policy expectations not matching ground realities.

6. Discussion

The findings highlight a disconnect between curriculum intent and classroom reality. While policy documents advocate for experiential and interdisciplinary science learning, schools remain adapted in conventional practices. Factors such as examination pressures, inadequate teacher training,and insufficient resources inhibit innovation.

The absence of contextual relevance in textbooks and examples limits student engagement. For example, a rural student studying chemical reactions may find the content abstract without local or environmental applications. Inclusivity remains a challenge—particularly for girls and tribal learners—who often internalize perceptions of science as "difficult" or "not for them."

These challenges necessitate systemic reforms that align curriculum, pedagogy, assessment, and teacher development with 21st-century educational goals.

7. Proposed Framework for Inclusive Science Education

Based on the study, a four-pillar framework is proposed:

7.1 Pedagogical Shifts

- Incorporate STEM/STEAM approaches to foster interdisciplinary learning.
- Use flipped classroom models to promote active learning outside school hours.
- Introduce gamification and simulations to enhance engagement in science concepts.
- Encourage student-led experiments and peer teaching to deepen understanding.
- Adopt formative assessments with real-time feedback instead of rote memorization.
- Promote collaborative learning through group projects and discussions.

7.2 Curriculum Reform

- Align curriculum with global sustainability goals (e.g., UN SDGs).
- Include indigenous knowledge systems to bridge traditional and modern science.
- Introduce future-ready skills like AI, data literacy, and climate science basics.
- Offer modular and flexible learning pathways for diverse student interests.
- Strengthen science communication skills through debates, reports, and presentations.
- Develop cross-curricular linkages with math, social studies, and language arts.

7.3 Teacher Empowerment

- Implement mentorship programs pairing experienced and new teachers.
- Train educators in adaptive teaching strategies for differently-abled students.
- Provide micro-credential courses on emerging topics like AI in education.
- Foster industry-academia collaborations for real-world teacher exposure.
- Encourage action research to test and refine innovative teaching methods.
- Establish digital resource hubs for sharing best practices and lesson plans.

7.4 Inclusive Infrastructure

- Set up mobile science labs for remote and underserved schools.
- Ensure assistive technologies for students with disabilities (e.g., Braille kits, audio tools).
- Develop virtual labs and AR/VR tools for immersive learning experiences.
- Partner with NGOs/corporates for low-cost science kits in rural areas.
- Upgrade ICT infrastructure with reliable internet and offline digital resources.

- Design gender-inclusive and culturally responsive learning spaces.

8. Policy Implications

To implement the proposed model, a multi-level policy approach is necessary:

1. Central and State Governments must allocate dedicated funding for science education infrastructure.
2. Teacher Education Institutions should update curricula to include inclusive, inquiry-based science pedagogy.
3. School Boards must reform assessments to evaluate competencies over rote knowledge.
4. Community Engagement should be institutionalized through partnerships with scientists, NGOs, and local leaders.

9. Conclusion

This study highlights the urgent need to reorient science education in India—particularly in diverse and underrepresented regions like Odisha—toward a more equitable, inclusive, and constructivist framework. The analysis clearly reveals a persistent gap between progressive educational policies and their actual implementation in classrooms. Despite students showing a strong interest in science, particularly in rural and tribal areas, their learning potential is constrained by outdated pedagogical practices, limited teacher training, infrastructural challenges, and a curriculum that often lacks relevance to local contexts.

To address these challenges, science education must go beyond textbook learning and embrace pedagogies that are inquiry-based, culturally contextualized, and student-centered. Equally essential is the professional development of teachers—not as a one-time intervention, but as a continuous and reflective process that equips them to navigate the complexities of modern science teaching. Access to technology, equitable resource distribution, and gender-sensitive approaches must also be integral components of any reform effort.

Furthermore, the study underscores the value of integrating local knowledge systems, especially in tribal and rural regions, to make science learning more meaningful and grounded in students' lived realities. Inclusion should not be limited to physical presence in the classroom but must reflect in curriculum design, pedagogy, teacher mindset, and assessment strategies.

In the 21st century, science education must cultivate not only scientific literacy but also critical thinking, collaboration, creativity, and socio-environmental responsibility. Reimagining science education is not merely an academic endeavor—it is a societal imperative that holds the key to sustainable development, innovation, and social justice.

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