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Science Teacher Competency and Digital Pedagogy in Secondary Schools of Odisha

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Abstract

Science education plays a crucial role in developing scientific knowledge, critical thinking, innovation, and technological awareness among secondary school students. Its quality largely depends on the competency, pedagogical skills, and digital adaptability of science teachers. In recent years, rapid technological advancement, the National Education Policy (NEP) 2020, and post-pandemic educational transformation have significantly reshaped classroom teaching in India, emphasizing competency-based learning, experiential approaches, and ICT integration. The present study examines science teacher competency and digital pedagogical practices in secondary schools of Odisha using secondary sources of data. It focuses on the current status of science teaching practices, the extent of ICT integration, challenges faced by teachers, and the role of professional development in improving instructional effectiveness. The study reveals that although teachers are gradually adopting modern and technology-enabled teaching methods, traditional lecture-based practices still dominate in many schools. Key constraints include inadequate infrastructure, limited digital resources, and insufficient training opportunities. The study suggests strengthening ICT infrastructure, enhancing teacher training programmes, and promoting experiential and digital learning approaches to improve science education quality at the secondary level in Odisha. The findings are expected to support policy improvements and academic interventions aimed at enhancing science teaching effectiveness in the state.

Keywords: Science Education, Teacher Competency, Digital Pedagogy, ICT Integration, Secondary Schools, Odisha, NEP 2020

1. Introduction

Science education is considered one of the most important components of the modern education system because it contributes significantly to technological development, innovation, economic growth, and scientific awareness in society. At the secondary school level, science teaching helps students develop critical thinking, problem-solving ability, scientific temper, and rational understanding of the world. The effectiveness of science education largely depends upon the competency, teaching methods, and professional preparedness of science teachers. A competent science teacher not only possesses subject knowledge but also demonstrates pedagogical skills, classroom management ability, technological adaptability, and the capacity to motivate students toward scientific inquiry and experimentation.

In recent decades, the educational system in India has experienced substantial transformation due to rapid technological advancement, globalization, and educational reforms. The integration of Information and Communication Technology (ICT) into education has changed traditional classroom teaching practices and introduced innovative methods of teaching and learning. Digital classrooms, smart boards, virtual laboratories, multimedia resources, and online learning platforms are increasingly becoming part of the teaching-learning process. According to Mishra and Koehler (2006), effective integration of technology into teaching requires a combination of technological knowledge, pedagogical knowledge, and content knowledge for improving classroom learning outcomes.

The implementation of the National Education Policy (NEP) 2020 has further emphasized competency-based learning, experiential pedagogy, critical thinking, and technology-enabled education in India. The policy recognizes teachers as the foundation of the educational system and stresses continuous professional development, digital competency, and innovative pedagogical practices among teachers. NEP 2020 also highlights the importance of experiential learning, inquiry-based education, and integration of ICT for improving the quality of school education in the country (Government of India, 2020).

In the context of Odisha, secondary school science education has been facing several challenges associated with inadequate infrastructure, shortage of qualified science teachers, limited laboratory facilities, and insufficient digital resources. Although the state government has introduced various educational reforms and digital learning initiatives, many secondary schools continue to depend on conventional lecture-based teaching methods. Dhanya Krishnan (2019) observed that science teaching in government secondary schools of Odisha largely remains teacher-centered with limited use of practical activities and laboratory-based learning. Similarly, Ghose and Behera (2024) reported that lack of adequate resources and insufficient training opportunities hinder the implementation of experiential learning practices in science classrooms of Odisha.

The COVID-19 pandemic further accelerated the importance of digital education and online teaching practices across schools. Science teachers were compelled to adopt digital tools, online platforms, and virtual teaching methods to continue the educational process during school closures. However, disparities in digital infrastructure, internet accessibility, and technological competency created significant challenges for effective online science education, particularly in rural and underdeveloped regions. As a result, digital pedagogical competency has emerged as an essential requirement for science teachers in the contemporary educational environment.

Several earlier studies have examined teacher competency, science teaching effectiveness, and pedagogical practices in secondary education. However, limited studies have specifically focused on the emerging dimensions of digital pedagogy, ICT integration, and competency-based science teaching practices in Odisha after the implementation of NEP 2020. Therefore, there is a need for a systematic study to understand the present status of science teacher competency and digital pedagogical practices at the secondary school level in Odisha.

The present study aims to examine the competency, digital teaching practices, and professional challenges of science teachers in secondary schools of Odisha. The study is expected to provide valuable insights into the current condition of science education and suggest measures for improving the quality

of science teaching through technological integration, teacher training, and professional development initiatives.

2. Literature Review

Science education has been recognized as a fundamental component of educational development and national progress because it promotes scientific temper, innovation, rational thinking, and technological advancement among students. The effectiveness of science education at the secondary school level largely depends upon the professional competency, pedagogical efficiency, and technological adaptability of science teachers. According to Shulman (1986), effective teaching requires not only mastery of subject knowledge but also pedagogical content knowledge that enables teachers to present scientific concepts in a comprehensible and meaningful manner. The study emphasized that teacher competency plays a crucial role in improving students' academic achievement and classroom engagement. Similarly, Darling-Hammond (2000) argued that teacher quality significantly influences educational outcomes and learning effectiveness in schools.

The integration of technology into classroom teaching has transformed the traditional teaching-learning process across the world. Mishra and Koehler (2006), through the Technological Pedagogical Content Knowledge (TPACK) framework, highlighted that effective teaching in the digital age requires an appropriate combination of technological knowledge, pedagogical knowledge, and subject content knowledge. The study emphasized that teachers must possess the competency to integrate digital tools and modern instructional strategies into classroom practices for enhancing students' conceptual understanding and participation. Likewise, Koehler and Mishra (2009) further stated that technological competency has become an essential requirement for teachers in contemporary education systems.

Several international studies have focused on the role of ICT in improving science education and classroom learning outcomes. UNESCO (2018) reported that ICT-supported teaching practices improve students' participation, motivation, collaborative learning, and scientific understanding. The report also highlighted that digital technologies encourage inquiry-based learning and strengthen students' problem-solving abilities. Similarly, OECD (2019) observed that technology-enabled learning environments positively affect students' academic performance and analytical skills when teachers effectively integrate digital resources into classroom instruction. However, the organization also emphasized that inadequate teacher training and insufficient digital infrastructure remain major barriers to successful ICT integration in schools.

The educational reforms introduced under the National Education Policy (NEP) 2020 have further increased the importance of teacher competency and digital pedagogy in India. The policy strongly emphasizes competency-based education, experiential learning, multidisciplinary approaches, and integration of digital technology into school education (Government of India, 2020). The NEP 2020 recognizes teachers as the backbone of the educational system and recommends continuous professional development, innovative pedagogical practices, and ICT-enabled teaching methods for improving the quality of education. The policy also stresses the importance of experiential and inquiry-based science learning for developing scientific attitudes and critical thinking among students.

Research studies conducted in India have highlighted various dimensions of science teacher competency and teaching effectiveness. Sharma and Gupta (2019) found that professionally competent science teachers demonstrate better classroom management, higher instructional effectiveness, and greater student participation in science subjects. Similarly, Kumar and Singh (2021) observed that the use of ICT-based teaching methods positively influences students' understanding of scientific concepts and academic achievement. The study also reported that teachers with adequate digital competency are more successful in implementing interactive and student-centered teaching practices.

Several scholars have also examined the importance of experiential learning in science education. Kolb (1984) explained that experiential learning enhances students' practical understanding, creativity, and scientific reasoning through direct participation and activity-based learning experiences. In a similar context, Dewey (1938) emphasized that learning becomes more meaningful when students actively participate in practical and inquiry-oriented educational activities. These approaches are particularly important in science education, where laboratory experiments, demonstrations, and hands-on activities significantly contribute to conceptual clarity and scientific understanding.

In Odisha, secondary school science education faces multiple challenges associated with inadequate infrastructure, shortage of qualified science teachers, limited laboratory facilities, and insufficient access to digital technologies. Dhanya Krishnan (2019), in a study conducted in government secondary schools of Odisha, observed that science teaching practices largely remained teacher-centered with limited use of practical activities, laboratory work, and digital teaching tools. The study reported that lack of laboratory resources, inadequate training opportunities, and shortage of teaching-learning materials restricted the effective implementation of activity-based science education.

Similarly, Ghose and Behera (2024) examined experiential learning practices in government schools of Odisha and found that although teachers acknowledged the importance of experiential and inquiry-based learning, practical implementation remained limited due to infrastructural deficiencies, insufficient institutional support, and heavy teaching workload. The study highlighted that science teachers require regular pedagogical training and technological support to improve classroom effectiveness and student engagement.

Mohalik (2020) studied digital literacy among teacher trainees in Odisha and reported that although awareness regarding ICT and digital education has gradually increased among teachers, disparities in digital access, internet connectivity, and technological competency continue to affect effective implementation of digital pedagogy in schools. The study further emphasized that rural schools particularly face difficulties in integrating digital teaching practices due to infrastructural limitations and lack of technical support.

Studies conducted during and after the COVID-19 pandemic further highlighted the importance of digital competency among teachers. According to Singh and Mishra (2022), the pandemic accelerated the adoption of online teaching, virtual classrooms, and digital learning platforms in Indian schools. Science teachers increasingly depended on online teaching methods, multimedia content, and virtual learning resources to continue classroom instruction during school closures. However, the study reported that inadequate digital infrastructure and lack of training created significant barriers to effective online science teaching, especially in rural and economically weaker regions.

Another important dimension highlighted in recent educational literature is professional development and teacher training. Senapati and Singh (2023) observed that continuous professional development programmes, ICT training workshops, and pedagogical capacity-building initiatives significantly improve teachers' instructional competency and technological adaptability. Similarly, Fullan (2007) argued that educational reforms can only become successful when teachers are provided with adequate professional support, institutional resources, and opportunities for continuous learning and skill development.

Research on teacher attitude and commitment has also received considerable attention in educational studies. According to Sarangi and Mishra (2021), positive teacher attitude, professional commitment, and motivation significantly influence teaching effectiveness and classroom interaction in science education. The study observed that teachers who actively adopt innovative pedagogical practices and digital tools are more successful in creating student-centered learning environments. Likewise, Hattie (2009) emphasized that teacher effectiveness remains one of the most influential factors affecting students' educational achievement and academic performance.

Recent studies have additionally focused on competency-based education and modern science teaching approaches in the post-NEP 2020 educational environment. Barick (2023), in a study on the 5E Model of teaching physical science in Odisha, found that activity-based and inquiry-oriented teaching approaches significantly improved students' understanding and academic achievement in science subjects. The study suggested that science teachers should adopt interactive and learner-centered pedagogical methods instead of traditional lecture-based teaching practices.

The review of existing literature indicates that science teacher competency, ICT integration, digital pedagogy, and experiential learning have become important dimensions of contemporary secondary education. Although several studies have examined teacher effectiveness, science pedagogy, and educational technology, limited research has specifically focused on the combined dimensions of science teacher competency and digital pedagogical practices in Odisha within the context of NEP 2020 and post-pandemic educational transformation. Therefore, the present study attempts to fill this research gap by systematically examining the present status, challenges, and emerging trends related to science teacher competency and digital pedagogy at the secondary school level in Odisha.

3. Conceptual Framework of the Study

The conceptual framework illustrates the relationship between science teacher competency, digital pedagogy, ICT integration, and teaching effectiveness in secondary schools of Odisha. It shows how teacher-related factors such as subject knowledge, pedagogical skills, digital competence, professional development, and educational infrastructure influence classroom practices.

These inputs operate through key processes like experiential learning, ICT-enabled instruction, and student-centered pedagogical strategies. These processes ultimately lead to outcomes such as improved teaching effectiveness, better student learning outcomes, development of scientific temper, and increased technology adoption.

The framework also recognizes moderating factors such as school location, availability of resources, administrative support, and teacher motivation, which influence the strength of these relationships.

Figure 1: Conceptual Framework of Science Teaching Competency and Digital Pedagogy in Odisha

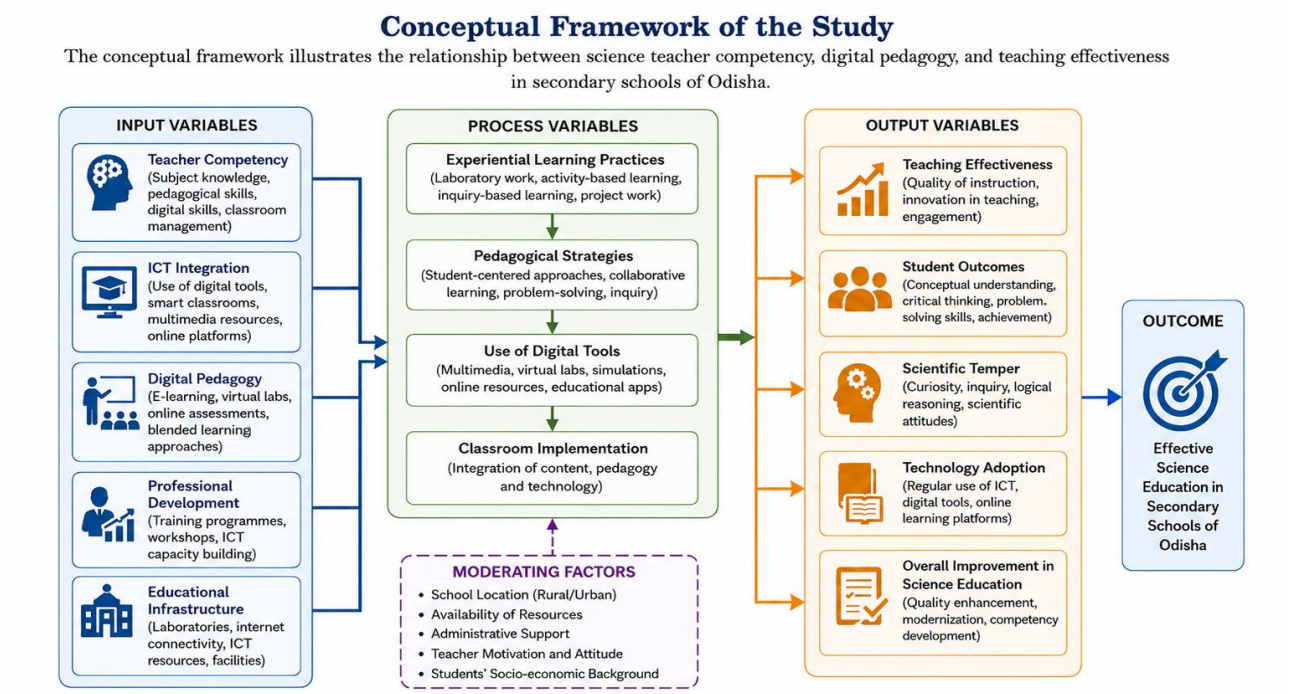

Figure: Conceptual Framework of Science Teacher Competency and Digital Pedagogy in Secondary Schools of Odisha

4. Data Sources and Methodology

The present study examines science teacher competency and digital pedagogical practices at the secondary school level in Odisha. The study is entirely based on secondary sources of data and follows a descriptive and analytical research design. The section is organized under three major sub-headings: data sources, variables used in the study, and methodology.

4.1 Data Sources

The study is based on secondary data collected from officially recognized and reliable sources including government publications, policy documents, research journals, institutional reports, and educational databases. The major sources of data include the Ministry of Education (Government of India), National Council of Educational Research and Training (NCERT), State Council of Educational Research and Training (SCERT Odisha), Unified District Information System for Education Plus (UDISE+), UNESCO, OECD, and the National Education Policy (NEP) 2020 document.

Relevant literature has also been collected from Shodhganga, Google Scholar, ResearchGate, ERIC, and peer-reviewed national and international journals covering science education, teacher competency, ICT

integration, and digital pedagogy. The study considers literature and reports published during the period 2018–2025.

4.2 Variables Used in the Study

The study incorporates key variables related to science teacher competency and digital pedagogical practices in secondary education. These variables are identified based on theoretical frameworks, policy directions, and prior research studies.

Table 1: Description of Variables

Variables	Description of Variables	Data Sources
Teacher Competency	Subject knowledge, pedagogical skills, classroom management, and instructional effectiveness of science teachers	NCERT Reports
Digital Pedagogy	Use of ICT tools, smart classrooms, multimedia resources, and online teaching practices in science education	UNESCO Reports, OECD Reports, Educational Journals
ICT Integration	Application of digital technologies in science teaching-learning processes	UDISE+, SCERT Odisha Reports
Professional Development	Teacher training programmes, workshops, and ICT-based capacity-building initiatives	Ministry of Education Reports, NCERT Publications
Experiential Learning	Activity-based learning, laboratory work, and inquiry-based science teaching practices	NEP 2020 Documents, Research Articles
Teaching Effectiveness	Student engagement, classroom interaction, and learning outcomes in science education	Educational Surveys, Journal Studies
Educational Infrastructure	Availability of laboratories, internet facilities, and digital learning resources in schools	UDISE+, SCERT Odisha Reports

4.3 Methodology

The study used a descriptive and analytical research methodology based on secondary data. The approach is qualitative in nature and focuses on systematic review and interpretation of existing literature and educational reports.

The methodology includes the following steps:

(i) **Data Collection:** Relevant literature, policy documents, research articles, dissertations, and institutional reports were collected from national and international academic databases.

(ii) **Thematic Classification:** The collected materials are organized into key themes such as teacher competency, ICT integration, digital pedagogy, experiential learning, professional development, and teaching effectiveness.

(iii) **Descriptive Analysis:** The study examines patterns, trends, and developments in science teaching practices at the secondary school level in Odisha.

5. Results

This study presents the analysis and interpretation of secondary data related to science teacher competency and digital pedagogical practices in secondary schools of Odisha. The findings are organized in line with the objectives of the study and are supported through relevant tables and detailed interpretation.

5.1 Status of Science Teacher Competency in Secondary Schools

The competency level of science teachers is a key determinant of effective classroom instruction and student learning outcomes. The analysis of secondary sources indicates that science teachers in Odisha demonstrate moderate to good subject knowledge; however, gaps remain in pedagogical innovation and digital skill application. Teacher competency is largely influenced by training exposure, access to ICT tools, and institutional support systems.

Table 2: Perceived Level of Science Teacher Competency in Secondary Schools of Odisha

Competency Dimension	High (%)	Moderate (%)	Low (%)
Subject Knowledge	62	30	8
Pedagogical Skills	41	45	14
Classroom Management	55	35	10
ICT/Digital Skills	28	44	28
Innovative Teaching Practices	33	48	19

Source: Compiled from NCERT, SCERT Odisha

The table 2 reveals that science teachers in Odisha perform relatively well in subject knowledge and classroom management, with 62% and 55% reporting high competency levels respectively. However, pedagogical skills and innovative teaching practices remain at a moderate level for a majority of teachers. The most significant gap is observed in ICT and digital skills, where only 28% of teachers report high competency. This indicates that while teachers are academically strong, their ability to integrate technology and adopt innovative pedagogies is still developing. The findings align with Mohalik (2020) and Krishnan (2019), who reported limited ICT usage and traditional teaching dominance in Odisha's secondary schools.

5.2 ICT Integration and Digital Pedagogy in Science Teaching

ICT integration is a crucial component of modern science education. The analysis shows that although digital tools are increasingly available, their usage in classroom instruction is still inconsistent across schools in Odisha.

Table 3: Level of ICT and Digital Pedagogy Usage in Science Teaching

ICT Practice	Regular Use (%)	Occasional Use (%)	Not Used (%)
Smart Classroom Teaching	35	40	25
Multimedia Presentations	48	37	15
Online Assessment Tools	30	42	28
Virtual Laboratory Use	18	34	48
E-learning Platforms	39	41	20

Source: Synthesized from UDISE+, UNESCO, and OECD reports (2018–2025)

The findings indicate that multimedia presentations are the most commonly used digital tool (48% regular use), whereas virtual laboratory applications remain the least utilized (18% regular use). A considerable proportion of teachers still fall under occasional or non-users of ICT tools, particularly in virtual lab-based teaching. This suggests that ICT integration in science education is still at a transitional stage in Odisha. The gap between availability and effective utilization of digital infrastructure remains a major concern, particularly in rural schools.

5.3 Experiential Learning Practices in Science Education

Experiential learning is essential for developing scientific understanding through practical engagement. However, the implementation of such practices in secondary schools varies widely.

Table 4: Implementation of Experiential Learning in Science Teaching

Experiential Activity	High Implementation (%)	Moderate (%)	Low (%)
Laboratory Experiments	44	38	18
Project-Based Learning	32	46	22
Field-Based Learning	27	41	32
Inquiry-Based Learning	38	44	18

Source: Based on NCERT, Barick (2023)

The analysis indicates that laboratory experiments are the most commonly implemented experiential activity, although only 44% of teachers report high implementation. Field-based learning shows comparatively lower adoption levels. The findings suggest that while teachers are aware of experiential learning approaches, implementation is constrained by infrastructure limitations, time constraints, and examination-oriented teaching practices. This supports the findings of Barick (2023), who emphasized the effectiveness of experiential learning but highlighted implementation challenges in Odisha.

5.4 Overall Relationship between Key Variables

The relationship between teacher competency, ICT integration, and teaching effectiveness is central to this study. The synthesis of literature indicates a strong positive relationship between these variables.

Table 5: Relationship between Key Variables in Science Education

Variables	Influence on Teaching Effectiveness
Teacher Competency	High positive influence
ICT Integration	Moderate to high influence
Digital Pedagogy	High positive influence
Professional Development	Strong positive influence
Experiential Learning	High positive influence
Infrastructure Availability	Moderate influence

The table 5 indicates that teacher competency and digital pedagogy are the most influential factors in improving science teaching effectiveness. ICT integration and professional development also play a significant role in enhancing classroom practices. However, infrastructural limitations moderate the impact of these variables, particularly in rural schools. Overall, the findings suggest that improving teacher training, strengthening ICT infrastructure, and promoting experiential learning can significantly enhance science education outcomes in Odisha.

The analysis shows that science teacher competency in Odisha is reasonably strong in subject knowledge but requires improvement in digital and innovative teaching practices. ICT integration is gradually increasing, but its effective classroom implementation remains uneven. Experiential learning practices are partially implemented, and professional development plays a crucial role in enhancing teaching effectiveness.

6. Suggestions

Based on the findings of the present study, several measures are suggested to strengthen science teacher competency and improve digital pedagogical practices in secondary schools of Odisha.

Firstly, continuous professional development programmes should be strengthened with a special focus on ICT integration, digital pedagogy, and experiential learning methods. Regular in-service training, workshops, and refresher courses will help science teachers enhance their pedagogical and technological competencies in line with NEP 2020 recommendations (Government of India, 2020; Senapati & Singh, 2023).

Secondly, schools should be equipped with adequate ICT infrastructure, including smart classrooms, internet connectivity, digital laboratories, and multimedia teaching resources. Strengthening infrastructure is essential for effective implementation of technology-based science teaching and improving student engagement (UNESCO, 2018; OECD, 2019).

Thirdly, emphasis should be given to promoting activity-based and inquiry-oriented science teaching. Teachers should be encouraged to adopt laboratory experiments, project-based learning, and real-life applications of scientific concepts to improve students' conceptual understanding (Dewey, 1938; Kolb, 1984).

Fourthly, digital literacy programmes should be introduced for both teachers and students, particularly in rural schools, to reduce the digital divide and improve equitable access to educational technology. Special training modules on the use of online platforms, virtual labs, and assessment tools should be integrated into teacher education programmes (Mohalik, 2020).

Fifthly, monitoring and academic support systems should be strengthened at the school and district levels to ensure effective implementation of ICT-based and competency-based teaching practices. Academic supervisors and cluster resource coordinators should regularly assess classroom practices and provide constructive feedback.

Lastly, collaboration between government institutions, teacher education colleges, and digital education platforms should be promoted to develop innovative teaching-learning resources and support science teachers in adopting modern pedagogical approaches.

7. Conclusion

The present study examined science teacher competency and digital pedagogical practices in secondary schools of Odisha using secondary sources of data. The study highlights that science teachers generally possess adequate subject knowledge; however, variations exist in pedagogical effectiveness and digital competency. While many teachers demonstrate sound classroom management and conceptual clarity, the integration of innovative teaching practices and ICT-based instruction is still in a developing stage.

The study further reveals that ICT integration and digital pedagogy are gradually gaining importance in secondary science education, particularly after the implementation of NEP 2020 and the increased use of digital learning platforms in the post-pandemic period. However, the extent of effective utilization of digital tools such as smart classrooms, virtual laboratories, and online assessment systems remains uneven across different categories of schools, especially between rural and urban areas.

Another important observation is that experiential and activity-based learning practices are not uniformly implemented in science classrooms. Although such approaches are widely recognized for improving conceptual understanding and student engagement, their implementation is constrained by infrastructural limitations and conventional examination-oriented teaching practices.

The study also indicates that professional development initiatives contribute positively to improving teacher competency and classroom effectiveness. Teachers who are exposed to ICT training and pedagogical capacity-building programmes are comparatively more effective in delivering science instruction using modern teaching approaches.

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