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Article

Impact of Digital Concept Mapping on Learning Achievement of Prospective Teachers in Physical Science Pedagogy

Piyali Bag[1], Priya Mitra [2]

[1]Department of Education, JIS University, 81, Nilgunj Road, Kolkata – 700109, West Bengal, India.
Email: piyalibag.edu@gmail.com.
[2]Department of Education, JIS University, 81, Nilgunj Road, Kolkata – 700109, West Bengal, India.
Email: priya.mitra@jisuniversity.ac.in.

Abstract: The integration of newfangled pedagogical frameworks in teacher education remains crucial for addressing persistent challenges in science teacher preparation. This quasi-experimental study examined digital concept mapping effectiveness versus traditional lecture-based methods on learning achievement in Pedagogy of Physical Science among B.Ed. students. The experimental intervention employed digital concept mapping, while the control group received conventional pedagogical instruction Data were gathered using a validated Learning Achievement Test designed to assess pedagogical knowledge, and the results were confirmed through statistical analyses. Findings revealed that digital concept mapping significantly enhanced learning achievement compared to traditional approaches. Experimental participants showed superior understanding of teaching methods, assessment techniques, and learning theories fundamental to effective physical science instruction. Gender analysis indicated equitable effectiveness across male and female participants. Results contribute valuable insights for B.Ed. curriculum reform, demonstrating how constructivist approaches can enhance pedagogical knowledge development and improve preparation of future educators for successful physical science classroom practice.
Keywords: Digital concept mapping, Pedagogy of Physical Science, Teacher Education, B.Ed. Programs, Meaningful Learning, Pedagogical Knowledge.

1. Introduction

The landscape of education in the twenty-first century is experiencing a profound and continuous transformation. This shift is largely influenced by rapid advancements in science and technology, changing societal expectations, and the increasing demand for individuals who possess not only knowledge but also the ability to think critically, solve problems, and adapt to new situations. In response to these evolving needs, educational systems across the world are gradually moving away from traditional teacher-centred approaches toward more learner-centred pedagogies. These modern approaches emphasize active engagement, conceptual understanding, and the construction of knowledge rather than the mere accumulation of facts. Such a transformation is especially crucial in the field of science education, where learners are expected to understand complex ideas, establish relationships among concepts, and apply their knowledge in real-life contexts.

Teaching physical science to prospective teachers involves fostering coherence, transferable understandings that future educators can confidently apply and teach. Prospective teachers balance deep content knowledge, the ability to present subject matters in logical sequence, pedagogical content knowledge (knowing how to teach particular concepts), and an appreciation for how learners construct scientific understanding. While some candidates begin training with partial knowledge, teacher education offers opportunities to strengthen conceptual frameworks—for example, helping trainees move from procedural fluency to principled explanations of phenomena. Teacher preparation programs that emphasize inquiry, reflection, and diagnostic assessment equip candidates to anticipate student thinking, design effective formative assessments, and scaffold learning toward deeper understanding. These capacities empower novice teachers to enact diagnostic teaching moves—eliciting student thinking, probing ideas with targeted questioning, and using formative evidence to guide instruction—and contribute to sustained improvement in science education even in large cohorts or resource-conscious settings.

Digital concept mapping provides a constructive way to make knowledge structure explicit and to surface reasoning processes. Concept maps encourage learners to identify key concepts, label the nature of relationships (for example cause–effect, part–whole, or generalization), and arrange ideas so connections are clear and meaningful. When maps are created using digital tools, several helpful features become available: nodes can link to simulations, images, short videos, or datasets; maps can be reorganized effortlessly to explore alternate framings; version

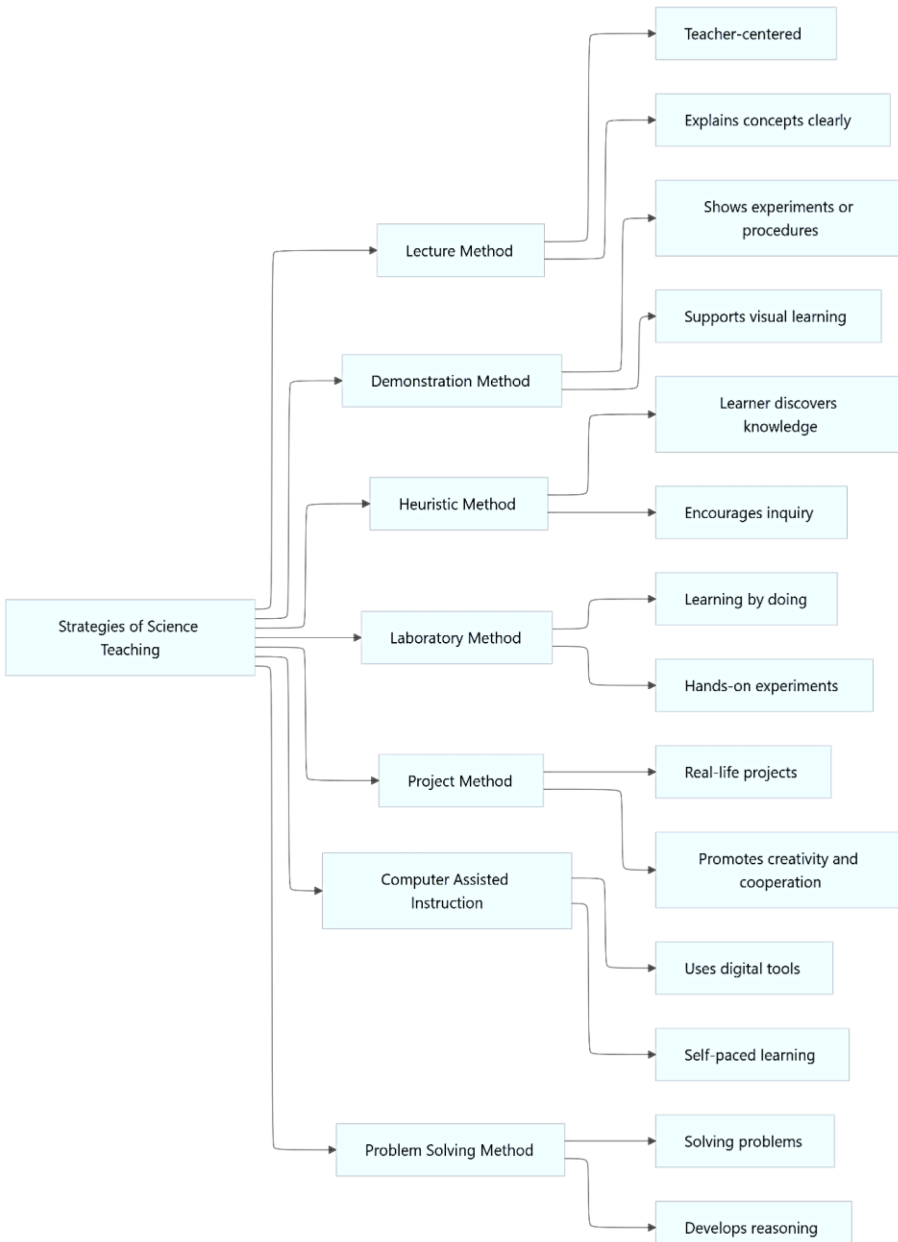

Figure 1: Example of Digital Concept Mapping on Strategies of Science Teaching

histories support reflection on learning progress; and comment threads enable collaborative critique. These affordances promote iterative refinement of understanding, support multimodal explanations, and foster rich formative feedback from instructors and peers. For prospective teachers, constructing and critiquing maps is a dual professional practice: it deepens content understanding while fostering pedagogical decision-making—selecting core concepts, sequencing explanations, and designing diagnostic prompts. Shared digital maps also serve as collaborative artifacts for co-designing lessons, negotiating representations, and rehearsing classroom explanations; they provide practical evidence of planning and reasoning during practicum assessments.

The expanding educational technology landscape offers intuitive mapping platforms with collaborative editing, cloud storage, and analytics that summarize connection patterns and engagement. These developments broaden how maps can be integrated into coursework: mapping can be used to elicit preconceptions before instruction, guide inquiry during laboratory activities, structure collaborative lesson design, and synthesize learning at the end of a unit. Instructors can use analytics to notice revision patterns, highlight sophisticated linking strategies, and support learners with targeted prompts. Mapping activities can take the form of low-stakes formative tasks, peer-reviewed assignments, or components of microteaching where prospective teachers present maps as part of lesson delivery. Implementation design is important: clear prompts, scaffolding that models mapping conventions, timely feedback, and alignment with assessment enhance the educational value of mapping. Research suggests particularly positive outcomes when mapping is part of a coherent instructional sequence—when learners receive explicit guidance on constructing meaningful propositions, engage in cycles of revision informed by feedback, and translate maps into classroom artifacts such as lesson outlines or assessment items.

A growing but evolving evidence base explores the benefits of concept mapping and its digital affordances in teacher education and science learning. Studies indicate that well-designed mapping activities support deeper conceptual organization and reflective practice, and that digital features (collaboration, multimedia embedding, and version history) enrich learning opportunities. Research continues to clarify how improvements in conceptual understanding translate into pedagogical competence—such as clearer lesson sequencing, more effective classroom explanations, and purposeful formative assessment choices. Continued study of mapping across diverse contexts will help identify which design elements yield the greatest educational return and how to adapt practice for varied institutional settings and cohort sizes. Gathering evidence on implementation factors—such as device access, instructor preparation, and integration with curriculum—supports scalable approaches that make positive outcomes accessible across programs.

This study examines the impact of structured digital concept mapping on learning achievement in a physical science pedagogy course for prospective teachers. It compares a scaffolded mapping approach—featuring explicit instruction on mapping strategies, peer critique, multimedia linking, and translation into lesson planning—with conventional instruction that relies on lectures, static notes, and traditional assessments. Outcomes include measures of conceptual understanding, retention, map quality and linkage accuracy, and indicators of pedagogical content knowledge such as identification of student ideas and clarity of lesson narratives. The study also documents implementation factors and participant experiences to identify features that support effective and sustainable use. By combining quantitative measures with reflective practice, the research aims to offer practical guidance for teacher educators seeking to strengthen both content mastery and instructional skill.

Research Rationale and Significance

Despite extensive theoretical support and promising preliminary research findings, systematic empirical investigation of digital concept mapping effectiveness in Pedagogy of Physical Science courses remains limited. Most existing studies have focused on content knowledge acquisition rather than pedagogical knowledge development, with insufficient attention to the unique learning needs and professional development requirements of prospective teachers. This study addresses these research gaps by providing rigorous empirical evidence regarding digital concept mapping effectiveness in pedagogical knowledge acquisition. The investigation examines not only learning achievement outcomes but also potential differential effects across gender groups—an important consideration for promoting equitable educational practices in science teacher preparation. The significance of this research extends beyond immediate pedagogical applications to encompass broader implications for teacher education reform, professional development, and educational policy. By demonstrating the effectiveness of constructivist pedagogies in teacher preparation, this study contributes to the growing evidence base supporting student-centred approaches that prioritize meaningful learning over rote memorization in professional education contexts.

2.Literature Review

Zamzam et al. (2026) found that Grade 10 advanced physics students using digital concept maps over six weeks significantly improved critical thinking—analysis, synthesis, evaluation—and understanding of complex topics like electricity and magnets, with benefits consistent across genders and schools, supporting digital maps for deep learning in science.

Czinczel et al. (2025) investigated how digital concept maps can reveal students' developing understanding of evolution, a conceptually difficult area prone to misconceptions. Using Learning Progression Analytics, the authors analysed students' maps produced during a digital unit on evolutionary factors to identify metrics that capture conceptual change and knowledge integration. Their work shows concept-mapping artifacts can be mined for formative insights such as the presence and accuracy of concept links, complexity of network structure, and progression of key ideas making students' conceptual development more visible to teachers and supporting targeted feedback within digital learning environments.

Kathumba & Simuja (2025) investigated whether concept mapping can develop computational thinking skills among postgraduate pre-service physical sciences teachers. Using a mixed-methods design with a six-lecture intervention, pre–post questionnaires, and reflective journals, they found participants improved notably in problem decomposition and pattern identification, while abstracting key concepts remained challenging. The study provides empirical evidence that concept mapping is a practical pedagogical tool for cultivating CT in science teacher education and recommends further research on its transferability to other disciplines and in-service contexts.

Elhilal (2025) explored how digital conceptual mapping affects students' mathematical concept formation and creative problem-solving by fostering cognitive flexibility. Using a mixed-methods design with 149 learners across three semesters, the study compared two mapping approaches (general-to-specific and specific-to-general) against a control. One-way ANOVA and effect-size measures showed both mapping strategies significantly improved students' understanding of contemporary mathematical concepts and enhanced flexible, creative problem-solving compared with the control. Reported effect sizes were large leading the author to recommend diversifying teaching methods to include digital concept maps.

Nipyrakis (2024) found no significant link between pre-service preschool teachers' digital concept-map quality and lesson-plan quality, but stronger focus consistency between maps and plans predicted better maps. Key quality indicators were concept count, propositions, cross-links, and hierarchy; teachers' views on digital vs. paper maps varied, supporting digital mapping's use in teacher training.

Tang & Tang (2024) investigated whether digital concept mapping (DCM) reduces learning anxiety and boosts motivation among nursing students in a physiology course. In a quasi-experimental pre–post design with 71 students (ages 16–18), DCM was used during 12 weeks of in-person instruction and six weeks of distance learning; assignments were completed individually and questionnaires plus assignment evaluations measured outcomes. Results showed DCM (accessed via mobile devices, tablets, notebooks) increased motivation and learning effectiveness especially in distance learning and lowered anxiety in both formats. The authors conclude DCM fosters self-regulated learning and recommend it as a practical framework to reduce stress and improve outcomes in varied (including international) settings.

Debbag, Çukurbaşı, and Fidan's pilot study examined 32 Turkish pre-service science teachers creating paper-based and digital mind maps (via Coggle) in technology education over six weeks. Participants reported positive views: mind maps reinforced, assessed, and visualized learning, made lessons more engaging, and were easy to use. Digital maps offered multimedia insertion, easy editing, and visual richness, though occasional technical issues arose; paper maps supported psychomotor development and experiential learning but were harder to edit and lacked multimedia support. Students envisioned using mind maps across topics (e.g., Vitamins, Earth and Universe, Systems) and for meetings, presentations, and brainstorming, supporting their integration into teacher education.

Alt et al. (2023) examined how students' goal orientations and learning approaches affect use of digital concept mapping in problem-based learning. Drawing on 129 undergraduates from institutions in Israel and Austria and using PLS-SEM, the study found digital concept mapping strengthens cognitive processing by helping learners identify relationships among arguments and understand topics more deeply. Mastery-approach and deep learners especially saw mapping as useful for self-regulation, while surface learners engaged less. The authors recommend scaffolding and demonstrating technology's benefits to involve surface learners in complex tasks so they recognize concept mapping's role in promoting meaningful, deep learning.

Guiral & Pifarré (2023) found that collaboratively building digital cognitive maps in an interactive, inquiry-scaffolded environment improved pre-service teachers' scientific knowledge, inquiry skills, and ability to represent complex concepts—increasing use of network-structured maps and supporting meaningful learning in teacher education.

Alt & NaamatiSchneider (2021) examined how digital concept mapping supported argumentation-based learning when a healthmanagement undergraduate course moved online during COVID19. Students used Mindomo (digital platform) to create maps with five arguments for solutions to an illstructured problem, then substantiated those claims; reflective journals were thematically analysed. Results showed shifts from passive to active learning, epistemic change, improved social perspectivetaking, stronger domain knowledge linked to prior experience, and effective online collaboration. The study suggests that combining constructivist activities with digital mapping fosters critical thinking, argumentation skills, and lifelonglearning capacities in healthmanagement education delivered online.

Rohles (2021) reframes digital concept mapping as a user-experience (UX) problem, arguing that tool design must support learners' cognitive work rather than add overhead. Through eight studies the dissertation identifies functional and experiential requirements for conceptmapping tools, shows how UX relates to psychological needs and intention to use, and develops scoring frameworks for map assessment. Key contributions include a threedimensional scoring framework, a profile of psychological needs for mapping, UX design guidelines, and methods for involving users in tool development all aimed at making digital concept mapping more usable, motivating, and pedagogically effective.

Bhattacharya and Mohalik (2020) review digital mind mapping software as a modern teaching-learning strategy that structures, analyzes, and retrieves ideas more productively than traditional notes. The paper outlines major software types, explains the step-by-step process of creating digital maps, and synthesizes benefits: simplified information for deeper understanding, direct learner engagement through map construction, and use as a brainstorming tool for visual idea diagrams. Because maps are editable, shareable, and can embed links or documents, they support collaboration, revision, and assessment across education levels. The authors conclude that institutions, teachers, and students can leverage these tools to enhance teaching, learning, and evaluation effectively.

Ahmed and Abdelraheem (2016) examined whether digital concept mapping improve learning in an undergraduate "Introduction to Educational Technology" course. Using two randomly chosen sections, they compared pre- and post-test achievement and attitudes. Results showed the digital-mapping group achieved higher post-test scores than the conventionally taught group, with female students in the experimental group outperforming males. No interaction effects among variables were detected. Students exposed to digital concept mapping reported positive attitudes toward the method, suggesting that integrating digital mapping tools can boost both understanding and learner receptivity in educational-technology instruction.

3.Objectives

1: To determine the effectiveness of Digital Concept Mapping compared to Traditional Instruction on learning achievement in Pedagogy of Physical Science among prospective teachers.

2: To investigate gender differences in Digital Concept Mapping effectiveness on learning achievement among prospective teachers.

4.Hypotheses

H_{01}: There is no significant difference in learning achievement between prospective teachers taught using Digital Concept Mapping and Traditional Methods.

H_{02}: There is no significant difference in learning achievement between male and female prospective teachers taught using Digital Concept Mapping.

5.Research Methodology

5.1. Research Design

This study employed a quasi-experimental, non-equivalent control group design with pre-test and post-test assessments to evaluate digital concept mapping effectiveness in Pedagogy of Physical Science teacher education. The research design was selected to balance experimental control with practical constraints inherent in educational settings, where random assignment of individual participants is often unfeasible due to existing course structures and administrative considerations.

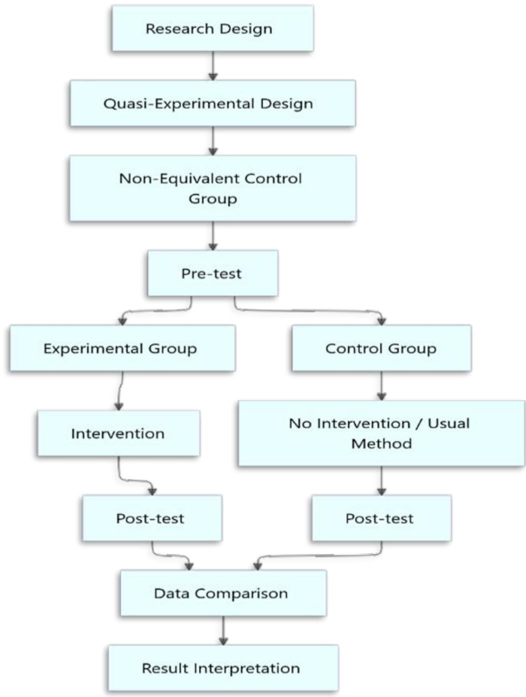

Figure 2: Research Design

5.2. Participants and Setting

Sixty prospective teachers enrolled in the B.Ed. course "Pedagogy of Physical Science" at the teacher training institution participated in this study.

5.3. Experimental Group: Digital concept mapping Instruction in Pedagogy of Physical Science

The experimental group participated in a comprehensive digital concept mapping intervention for the B.Ed. course "Pedagogy of Physical Science", covering essential pedagogical concepts for effective physical science teaching.

Control Group: Traditional Pedagogy of Physical Science Instruction

The control group received conventional instruction in Pedagogy of Physical Science through lecture-based methods typical of B.Ed. teacher education programs. Content delivery emphasized theoretical knowledge of teaching methods.

5.4. Instrumentation

Learning Achievement Test for Pedagogy of Physical Science. Learning Achievement Test consist of 40 MCQ developed specifically for the B.Ed. Pedagogy of Physical Science course, assessing understanding of teaching methods, learning theories, assessment strategies, and classroom management techniques

Psychometric Properties: Pilot testing with B.Ed. students (n = 20) yielded high reliability (Cronbach's α = 0.85) and validity of Achievement.

5.5. Data Analysis

Data were analysed using means, standard deviations and paired t-tests.

6. Data Analysis and Interpretation

Objective wise analysis:

6.1. *Objective 1*: To determine the effectiveness of digital concept mapping compared to traditional instruction on learning achievement in Pedagogy of Physical Science among prospective teachers.

Related to Null Hypothesis 1

H_{01}: There is no significant difference in learning achievement between prospective teachers taught using digital concept mapping and traditional methods.

Table 1: Paired Samples Analysis of Pre-test to Post-test Changes Within Groups

Group	Pre-test M (SD)	Post-test M (SD)	Mean Difference	SD of Difference	t-value	df	Sig. (2-tailed)
Experimental	14.67 (3.24)	22.13 (3.08)	7.46	3.63	11.26	29	< 0.001
Control	14.50 (3.31)	19.70 (3.30)	5.20	4.94	5.77	29	< 0.001

Interpretation

In the table 1, The within-group analysis demonstrated that both instructional approaches produced statistically significant learning gains in Pedagogy of Physical Science, but with markedly different magnitudes. The experimental group's improvement of 7.46 points [$t(29) = 11.26$, $p < 0.001$], indicating that digital concept mapping produced substantial and consistent gains in pedagogical knowledge across participants. The control group also achieved significant improvement [5.20 points, $t(29) = 5.77$, $p < 0.001$], but the digital concept mapping intervention produced 43% greater learning gains in understanding of teaching methods, assessment strategies, and learning theories essential for effective physical science instruction.

Null Hypothesis 1 (H_{01}) was REJECTED. There was sufficient statistical evidence to conclude that digital concept mapping instruction was significantly more effective than traditional instruction for enhancing learning achievement in Pedagogy of Physical Science among prospective teachers.

6.2. **Objective 2**: To investigate gender differences in digital concept mapping effectiveness on learning achievement among prospective teachers.

Related to Null Hypothesis 2

H_{02}: There is no significant difference in learning achievement between male and female prospective teachers taught using digital concept mapping.

Gender Equity Analysis in Digital concept mapping Effectiveness

Table 2: Gender Comparison Analysis Within Experimental Group

Gender	N	Pre-test M (SD)	Post-test M (SD)	Gain Score M (SD)
Male	15	14.73 (3.45)	21.88 (2.73)	7.15 (3.82)
Female	15	14.60 (3.07)	22.43 (3.27)	7.83 (3.51)

Table 3: Independent Samples t-Test Results for Gender Comparison

Measure	t-value	df	Sig. (2-tailed)	Mean Difference	SE Difference
Pre-test Scores	0.12	28	0.91	0.13	1.14
Post-test Scores	0.35	28	0.73	-0.55	1.58
Gain Scores	0.42	28	0.68	-0.68	1.61

Interpretation

In the table-2 &3, The gender analysis provided conclusive evidence that digital concept mapping effectiveness in Pedagogy of Physical Science transcended gender differences, supporting equitable educational outcomes in teacher preparation. Post-intervention analysis revealed no significant gender differences in pedagogical knowledge acquisition [$t(28) = 0.35$, $p = 0.73$], with both groups performing at similarly high levels. Most importantly, analysis of gain scores showed no significant gender differences [$t(28) = 0.42$, $p = 0.68$], with both male (7.15-point gain) and female (7.83-point gain) participants achieving substantial and comparable improvements in understanding of teaching methods, learning theories, and assessment strategies essential for effective physical science instruction.

Null Hypothesis 2 (H_{02}) was ACCEPTED. There was insufficient statistical evidence to conclude that there were significant gender differences in the effectiveness of digital concept mapping for learning achievement in Pedagogy of Physical Science. The intervention was equally effective for both male and female prospective teachers.

7. Discussion

The results conclusively demonstrate that digital concept mapping significantly enhances learning achievement in Pedagogy of Physical Science among prospective teachers compared to traditional lecture methods. The experimental group's superior post-test performance represents not merely statistical significance but substantial practical importance for teacher preparation. The substantial within-group improvement in the experimental condition compared to the control group suggests that digital concept mapping provides additional learning benefits in pedagogical knowledge acquisition beyond natural maturation or repeated exposure to teaching concepts. The effectiveness can be attributed to digital concept mapping's unique cognitive demands in pedagogical contexts, which require teacher candidates to actively organize, relate, and hierarchically structure their understanding of teaching methods, learning theories, and assessment strategies rather than passively receive information about pedagogical practices. This active construction of pedagogical knowledge aligns with constructivist principles that emphasize the importance of meaningful learning in professional development.

The research findings have immediate practical applications for B.Ed. programs seeking to enhance both pedagogical knowledge acquisition and teacher preparation effectiveness. The dual benefits of enhanced learning and pedagogical modelling make digital concept mapping particularly valuable for teacher education contexts, where prospective teachers must develop both theoretical understanding and practical implementation skills. The gender-neutral effectiveness supports digital concept mapping as an equitable instructional strategy that can benefit diverse populations of teacher candidates without differential impacts based on gender. This finding has important implications for science teacher education, where promoting inclusive learning environments is essential for developing effective educators who can serve diverse student populations. The findings provide empirical support for constructivist approaches to teacher education that emphasize active knowledge construction, collaborative learning, and reflective practice. The success of digital concept mapping in enhancing pedagogical knowledge development demonstrates that theoretical principles of meaningful learning are applicable to professional education contexts and can produce measurable improvements in teacher preparation outcomes.

8. Conclusion

This rigorous quasi-experimental investigation provides compelling evidence that digital concept mapping significantly enhances learning achievement in Pedagogy of Physical Science among prospective teachers compared to traditional lecture-based instruction. The research yielded substantial learning gains that demonstrate both statistical significance and practical educational importance for teacher preparation. Empirical Validation: The study provides quantitative evidence supporting digital concept mapping's effectiveness in pedagogical knowledge acquisition, addressing gaps in teacher education research. Results demonstrate equal benefits for male and female prospective teachers, supporting equitable pedagogical practices in science teacher preparation. Practical Applications: Findings provide actionable insights for teacher educators seeking evidence-based strategies that enhance both pedagogical learning and model effective teaching practices. The implications extend beyond immediate instructional applications to encompass broader questions about effective teacher preparation in higher education. The success of digital concept mapping supports educational reform movements emphasizing student-centred, constructivist pedagogies that prioritize deep understanding over surface-level knowledge acquisition in professional education contexts.

In addition to these findings, the study brings out the wider educational value of digital concept mapping as a meaningful approach in teacher education. The strong improvement in learning shows that when prospective teachers actively work with ideas—organizing them, linking them, and reflecting on them—their understanding becomes clearer and more lasting. This supports the idea that learning is most effective when individuals are involved in building their own knowledge rather than simply listening and memorizing. Another important point is that the positive impact of digital concept mapping was consistent across different groups of learners, suggesting that it works well for a wide range of students and supports inclusive learning environments. Beyond improving academic performance, digital concept mapping also helps prospective teachers grow professionally, as they experience a practical teaching strategy that they can later use in their own classrooms. This not only improves their subject understanding but also builds confidence in using student-centred approaches instead of relying only on traditional lectures. The findings also have important implications for how teacher education programs are designed. Including digital concept mapping in regular teaching can make learning more interactive, reflective, and connected to real classroom situations. It helps future teachers see how theory links with practice, which is often a major challenge in teacher preparation. At the same time, the use of digital concept mapping fits well with current educational goals that focus on developing critical thinking, problem-solving ability, and deeper understanding rather than surface-level learning. Overall, the study highlights the importance of giving prospective teachers meaningful learning experiences, as these shape how they will teach in the future. By helping them understand concepts more clearly and equipping them with useful teaching strategies, digital concept mapping plays an important role in preparing thoughtful, flexible, and effective teachers for modern classrooms.

9. Contribution to the field

The findings provide practical suggestions for redesigning B.Ed. programmes by showing how constructivist strategies, especially digital concept mapping, can help prospective teachers build stronger understanding of physical science and develop more thoughtful teaching practices. When studentteachers draw and revise concept maps around physics and chemistry ideas, they begin to see how concepts connect, notice where their own understanding is shaky, and plan lessons that are more logical and meaningful for learners. This fits well with constructivist ideas that urge teachers to build on what students already know and support them in constructing their own understanding rather than simply copying or memorising.

By integrating digital concept mapping into sciencepedagogy courses, teachereducation institutions can nudge teacher educators to use more interactive, discussionbased and visually supported methods. Prospective teachers carry this experience into school classrooms, where they can use concept maps to clarify difficult topics, check students' thinking, and help learners reflect on how ideas fit together. Overall, this orientation moves B.Ed. training away from heavily lecturedriven, factcentred teaching toward a more responsive, researchinformed model that prepares future teachers to handle the real challenges of teaching physical science in diverse school settings.

10. Declaration of Conflicting Interests

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12. ORCID IDs

Piyali Bag - https://orcid.org/0000-0002-5263-0085

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