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DIAGNOSING PEDAGOGICAL AND TECHNOLOGICAL NEEDS FOR INQUIRY-BASED TEACHING: A PARTICIPATORY ACTION RESEARCH STUDY OF SECONDARY TEACHERS

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Abstract:

This study investigates the potential of integrating Lesson Study within a Critical Participatory Action Research (CPAR) framework to transform science teachers' pedagogical practices in technology-integrated, inquiry-based education. Drawing upon the Technological Pedagogical Content Knowledge (TPACK) framework, Vygotsky's Sociocultural Theory, and Mayer's Cognitive Theory of Multimedia Learning (CTML), the research seeks to achieve three objectives: (1) to explore how Lesson Study enhances teachers' instructional practices in science education, (2) to co-develop contextually relevant and technologically integrated teaching materials, and (3) to identify challenges and opportunities in fostering teacher collaboration and technology integration. Adopting a qualitative research methodology, the study engages 12 secondary science teachers through iterative Lesson Study cycles of planning, implementation, observation, and reflection. Data are collected through classroom observations, reflective journals, semi-structured interviews, focus groups, and artifact analysis. Preliminary findings highlight a significant shift in teachers' instructional approaches, with increased confidence in using technology and adopting inquiry-based methods. Collaborative processes fostered professional growth and enabled the development of teaching materials that align with curriculum standards and address student needs. However, barriers such as time constraints, varying levels of technological expertise, and infrastructure limitations underscore the need for systemic support. Triangulated data provide robust evidence for the effectiveness of Lesson Study within CPAR in addressing pedagogical and systemic challenges. This study contributes to the field by offering a scalable and replicable framework for professional development, advancing the integration of technology and inquiry-based learning in science ed.

Keywords:

Inquiry-Based Science Education, Technological Pedagogical Content Knowledge (TPACK), Lesson Study, Teacher Professional Development, Critical Participatory Action Research (CPAR)

Introduction

The evolving demands of 21st-century education necessitate transformative approaches in science instruction. Inquiry-based science education, which emphasizes active learning, critical thinking, and problem-solving, has emerged as a leading pedagogical framework (Bybee, 2014). Unlike traditional instructional models focused on passive knowledge transmission, this approach engages students in authentic scientific inquiry, enabling them to construct a deeper understanding of scientific concepts through investigation and reflection.

Parallel to this pedagogical shift, technological advancements have introduced tools that hold immense potential to enhance inquiry-based learning. These include simulations, virtual laboratories, data visualization platforms and collaborative online environments, which provide dynamic ways for students to interact with complex scientific phenomena. However, integrating these technologies into classroom practices remains a significant challenge. Many teachers lack the necessary Technological Pedagogical Content Knowledge (TPACK) to effectively align technology with pedagogical and content-specific goals (Mishra & Koehler, 2006). Furthermore, limited professional development opportunities often leave teachers underprepared to optimize the benefits of these tools.

Lesson Study a structured model for collaborative professional development provides a promising avenue for addressing these challenges. Through iterative cycles of planning, implementation, observation, and reflection, Lesson Study fosters the continuous refinement of instructional practices and the co-construction of pedagogical expertise (Lewis & Hurd, 2011). When embedded within a Critical Participatory Action Research (CPAR) framework, Lesson Study addresses systemic barriers and facilitates the development of contextually relevant, technology-integrated instructional practices. This study explores the integration of Lesson Study within CPAR to enhance science teachers' pedagogical practices and co-create effective teaching materials tailored to the demands of contemporary science classrooms.

Statement of the Problem

Despite widespread recognition of the transformative potential of inquiry-based and technology-enhanced science education, its effective implementation remains hindered by persistent and multifaceted barriers (Bybee, 2014; NRC, 2012). These challenges undermine the capacity of teachers to adopt innovative pedagogical practices and limit students' engagement in 21st-century scientific learning (Saavedra & Opfer, 2012; OECD, 2018).

One of the most significant barriers is teacher preparedness. Many science teachers lack access to professional development programs that equip them with the necessary skills, knowledge, and confidence to integrate technology effectively into inquiry-based teaching (Fishman et al.,

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2003; Voogt et al., 2015). As Darling-Hammond et al. (2017) highlight, insufficient training opportunities leave teachers ill-prepared to leverage digital tools and implement student-centered, inquiry-driven instructional strategies. The lack of sustained professional learning inhibits teachers' ability to navigate the intersection of technology, pedagogy, and content knowledge, as outlined in the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006; Niess, 2005). Without adequate preparation, teachers are unable to fully embrace the pedagogical shifts required for inquiry-based education in a digital age.

Resource deficiencies further exacerbate the problem. There is a notable scarcity of high-quality, adaptable instructional materials that align with the principles of inquiry-based pedagogy while effectively leveraging technological tools (Krajcik & Shin, 2014). Hofstein and Lunetta (2004) emphasize that many existing resources fail to meet the dual demands of fostering inquiry-based learning and integrating advanced technologies, leaving teachers with limited options to engage students in meaningful scientific inquiry. This scarcity is particularly pronounced in diverse classroom contexts where teachers require flexible and contextually relevant materials tailored to their unique instructional environments (Windschitl, 2003; Bell et al., 2010). Consequently, teachers often resort to traditional methods that do not reflect the dynamic and interactive nature of modern science education.

In addition to teacher- and resource-related challenges, systemic issues present significant obstacles to the effective implementation of technology-enhanced inquiry-based education. Institutional resistance to pedagogical innovation, inadequate technological infrastructure, and inequitable access to digital resources continue to stifle progress (Koehler & Mishra, 2009; Ertmer & Ottenbreit-Leftwich, 2010). These systemic constraints create disparities in educational opportunities, perpetuating inequities in under-resourced schools and communities (Schleicher, 2012). Furthermore, the lack of structural support for collaborative professional development perpetuates isolated teaching practices, limiting opportunities for reflective practice, collective problem solving and pedagogical innovation (Borko, 2004). Without addressing these systemic challenges, efforts to integrate technology and inquiry-based approaches will remain fragmented and unsustainable.

To address these pressing challenges, this study employs Lesson Study and Critical Participatory Action Research (CPAR) as collaborative frameworks for professional development. These methodologies prioritize sustained, iterative cycles of co-creation, observation, and reflection, empowering teachers to design and implement instructional practices that are both technologically innovative and responsive to their unique educational contexts. By leveraging the principles of collaboration and critical inquiry, this research aims to bridge the gap between theory and practice, fostering sustainable pedagogical transformation and equipping teachers to meet the demands of 21st-century science education.

Theoretical and Conceptual Framework

This research is underpinned by three interrelated theoretical frameworks: Technological Pedagogical Content Knowledge (TPACK), Vygotsky's Sociocultural Theory, and Mayer's Cognitive Theory of Multimedia Learning (CTML). Together, these frameworks provide a comprehensive foundation for addressing the complexities of integrating technology into inquiry-based science education. Each framework complements the others, ensuring a

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multidimensional and robust approach to enhancing pedagogical practices and developing effective teaching materials.

The Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006) highlights the interplay between technology, pedagogy, and content knowledge. It provides a theoretical lens through which teachers can design instructional strategies that effectively integrate technological tools with pedagogical goals and disciplinary content. TPACK emphasizes the need for teachers to develop a nuanced understanding of how these three domains interact dynamically to facilitate meaningful learning experiences. This framework is especially relevant to the study as it addresses the critical gaps in teachers' knowledge and preparedness, a major barrier to implementing technology-enhanced inquiry-based learning. By utilizing the TPACK framework, this research aims to guide the co-creation of teaching practices and materials that are both pedagogically sound and technologically innovative.

Vygotsky's Sociocultural Theory (1978) underscores the importance of social interaction and collaboration in learning. Key concepts such as the Zone of Proximal Development (ZPD) and scaffolding are particularly relevant to the collaborative and iterative nature of Lesson Study. The ZPD which represents the distance between what a learner can achieve independently and what they can accomplish with guidance, parallels the professional growth experienced by teachers engaged in collaborative professional development. The scaffolding provided by Lesson Study cycles through planning, observation, and reflection enables teachers to expand their pedagogical expertise and address the challenges of integrating technology into their teaching. Moreover, Vygotsky's emphasis on the sociocultural context aligns with this study's participatory action research approach which prioritizes collaboration and contextual relevance in educational practices.

The Cognitive Theory of Multimedia Learning (CTML) (Mayer, 2002) provides evidence based principles for designing instructional materials that optimize cognitive processing. Mayer's theory posits that effective multimedia learning occurs when instructional materials are designed to minimize extraneous cognitive load, foster essential cognitive load, and enhance germane cognitive processing. The dual channel processing principle which suggests that humans process visual and auditory information separately is particularly critical for this study's focus on developing multimedia teaching resources. CTML ensures that the co-created teaching materials adhere to principles of effective cognitive design enabling students to engage deeply with scientific content in ways that align with how they learn most effectively. By integrating this framework, the study ensures that the technological resources designed through Lesson Study are not only innovative but also grounded in cognitive science principles. By synthesizing these three theoretical frameworks, this research ensures a robust and multidimensional approach to addressing the challenges of technology-integrated, inquiry-based science education. TPACK provides a lens for integrating content, pedagogy and technology; Vygotsky's Sociocultural Theory supports the collaborative and iterative development of professional expertise; and CTML ensures that multimedia resources are designed to maximize cognitive engagement. Together, these frameworks enable this study to address systemic barriers, develop effective teaching practices, and foster sustainable pedagogical transformation.

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Research Question

This study is guided by the following research questions: 1) How does the integration of Lesson Study within CPAR enhance science teachers' practices in technology-integrated, inquiry-based education? 2) What contextually relevant teaching materials can be co-developed to address the needs of 21st-century science classrooms? and 3) What challenges and opportunities arise in fostering teacher collaboration and technology integration through Lesson Study and CPAR?

Methodology

This study adopts a qualitative research design rooted in a Critical Participatory Action Research (CPAR) framework. CPAR is characterized by its collaborative, iterative, and action-oriented approach, making it highly suitable for addressing complex, context-specific educational challenges (Kemmis et al., 2014; McTaggart, 1997; Somekh, 2006). Within this framework, Lesson Study serves as the primary mechanism for professional development enabling science teachers to co-create, implement, and refine pedagogical practices in a systematic and collaborative manner (Dudley, 2013).

Lesson Study cycles are iterative and structured, comprising four stages: planning, implementation, observation, and reflection. During the planning stage, teachers collaboratively design lessons that integrate technology into inquiry-based science education. These lessons are implemented by participants while others observe to gather qualitative data on student engagement, learning outcomes, and the practical application of the teaching strategies (Lewis et al., 2006; Cerbin & Kopp, 2006). Observations are followed by reflective sessions where participants analyze the effectiveness of the lessons and propose refinements for subsequent iterations.

The CPAR framework ensures that participants are not passive recipients of professional development but active co-researchers. This participatory approach democratizes the research process, fostering a sense of ownership and collective responsibility for pedagogical innovation. As Kemmis et al. (2014) argue, CPAR not only facilitates immediate improvements in practice but also contributes to long-term systemic change by embedding reflective inquiry within the professional culture of teachers (Zuber-Skerritt, 2013; Zeichner, 2008).

Participants

This study recruited secondary science teachers from a range of diverse educational contexts to ensure a broad representation of perspectives and expertise. Participants were selected based on their willingness to engage in collaborative professional development initiatives and their prior experience or interest in technology-integrated and inquiry-based pedagogy (Desimone, 2009; Voogt et al., 2015). Voluntary participation was prioritized as an inclusion criterion to foster authentic engagement and sustained commitment to the research process (Creswell & Poth, 2018). The core participant group comprised 12 secondary science teachers which provided a balance between diversity of perspectives and a manageable size for effective collaboration within Lesson Study cycles (Lewis & Hurd, 2011; Kemmis et al., 2014; Lieberman & Mace, 2010). To gain deeper insights into collaborative dynamics and shared experiences, 2–3 focus groups were conducted each involving 4–6 participants (Morgan, 1997). Additionally, classroom observations were undertaken in 1–2 classrooms per teacher to evaluate the practical implementation of co-developed teaching materials and to examine the

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impact of the intervention within authentic instructional settings (Lewis, 2002; Stigler & Hiebert, 1999).

Instruments

This study employs a comprehensive suite of qualitative and quantitative instruments to address the research questions with a focus on technology integration and inquiry-based teaching practices. Data collection methods include classroom observations to document realtime practices, reflective journals that capture teachers' personal insights on professional growth and challenges and semi-structured interviews exploring their experiences and changes in pedagogical approaches. An artifact analysis rubric is used to evaluate the alignment of co-developed teaching materials with inquiry-based and technology-enhanced principles. Additionally, collaborative design session notes document the process of co-developing teaching materials, highlighting challenges and decision making. Teacher feedback surveys gather perceptions of the relevance, usability, and effectiveness of these materials, while focus groups provide collective insights into collaboration dynamics, challenges and opportunities. Participant diaries offer ongoing reflections on collaboration and technology integration and a barriers and opportunities questionnaire identify specific challenges and potential areas for improvement.

To ensure the validity and credibility of the findings, the study incorporates several strategies. Triangulation is employed by cross referencing data from multiple instruments such as observations, journals, and interviews to ensure consistency and depth. Member checking involves participants validating the researcher's interpretations of the data while peer review engages experts in science education to assess the instruments and findings for credibility. Reflexivity is maintained through reflective journals, allowing researchers to document and address potential biases that might influence the study.

The data analysis follows a structured approach. Qualitative data will undergo thematic analysis using Braun and Clarke's (2006) framework to identify patterns and themes. Co-developed teaching materials will be assessed using a predefined rubric while descriptive statistics will be used to analyze survey and questionnaire responses. Triangulation will also play a critical role in integrating data from multiple sources, ensuring a comprehensive and nuanced understanding of the research findings.

Findings

Thematic analysis of data from reflective journals, classroom observations, interviews, focus groups, and artifact analysis revealed four interrelated domains of teacher need: pedagogical, technological, professional development, and systemic/institutional. These themes reflect both individual challenges and structural constraints and they collectively informed the design and enactment of the Lesson Study–CPAR intervention cycles.

Pedagogical Needs: Uncertainty in Designing Inquiry-Based Instruction

A significant finding emerging from participant narratives was the persistent uncertainty in implementing inquiry-based science instruction. While teachers expressed philosophical alignment with the ideals of student-centered inquiry, they often struggled to operationalize these practices in their classrooms.

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"I know students should be asking questions and exploring, but it's hard to structure those activities without losing focus or control." — Teacher D, interview

Most participants reported defaulting to direct instruction methods, particularly when faced with time constraints or high-stakes assessment pressures. Inquiry-based strategies such as hypothesis formulation, guided experimentation, and collaborative argumentation were rarely fully enacted.

"Sometimes I try inquiry, but it feels messy. Students are unsure, I'm unsure, and we often fall back into lecture mode." — Teacher E, journal

Teachers also highlighted a lack of concrete exemplars and scaffolding frameworks for structuring inquiry activities that balance student autonomy with instructional guidance. These gaps suggest a need for collaborative lesson design processes that build collective expertise in inquiry pedagogy.

Technological Needs: From Tool Use to Pedagogical Intentional Integration

While access to digital tools (projectors, simulations, tablets, iPads) was generally adequate across participating schools, their instructional use remained superficial and fragmented. Teachers commonly described technology as an add-on rather than as a medium for deeper inquiry.

"I use tech every day, but it's mostly for slides, videos or quick checks. It's not really integrated into how students learn science." — Teacher F, focus group

Many participants lacked the conceptual tools to evaluate the cognitive affordances of different technologies. For example, simulations were often used passively, without structured inquiry prompts or follow-up activities that would engage students in sense-making or analysis.

"I like using virtual labs, but I'm not sure how to connect them to deeper thinking or what questions to ask."— Teacher H, journal entry.

This pattern revealed a limited enactment of TPACK, particularly in connecting technological tools to disciplinary content through sound pedagogy. Teachers frequently asked for guidance not just on how to use tools, but on why and when to use them within inquiry-based lessons.

"There's so much tech out there, but I need a way to decide what fits the goal of the lesson and not just what looks good." — Teacher M, interview.

Moreover, participants demonstrated little awareness of Cognitive Theory of Multimedia Learning (CTML) principles. Several acknowledged inadvertently overloading students with dense slides, long videos, or disjointed materials.

"I put everything into the slides I prepared including text, diagrams, instructions, but students seem more confused than helped." — Teacher J, observation reflection.

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This finding indicates an urgent need for professional learning on multimedia design, including the use of clips, signaling, segmentation and visual clarity to support student cognition. The absence of these strategies not only reduces instructional effectiveness but may also contribute to student disengagement.

Lastly, technology was rarely used to support student agency in the inquiry process, such as collaborative data analysis, hypothesis testing, or digital modeling.

"I hadn't really thought of using tech to let students make their own models or test ideas. We mostly use it to deliver content." — Teacher B, focus group.

Professional Development Need: Desires for Collaborative, Practice Embedded Learning

Participants expressed deep dissatisfaction with their previous professional development experiences, describing them as fragmented, one-size-fits-all and disconnected from classroom realities.

"Most PD is someone talking at us about a tool or theory, but there's no time to try it, reflect on it, or see it in action." — Teacher G, interview.

There was a strong desire for collaborative, contextually grounded PD that aligns with the demands of their teaching and allows for ongoing dialogue, reflection, and refinement.

"I learn more from planning a lesson with colleagues than from any workshop I've attended." — Teacher L, journal.

Teachers highlighted the importance of PD that fosters shared ownership, promotes iterative cycles of practice, and is embedded in their school contexts.

"It's not about someone telling us what works. It's about figuring out what works here, with our students, in our reality." — Teacher A, focus group.

Lesson Study was seen as a compelling alternative that providing time, structure and peer feedback to collectively improve practice.

Systematic and Institutional Needs: Navigating Structural Barriers to Innovation

Beyond individual challenges, participants identified systemic constraints that inhibit instructional innovation. Chief among these were: i) lack of protected collaboration time, ii) rigid curriculum pacing guides and assessment mandates, iii) inequitable access to digital infrastructure across classrooms and iv) limited administrative encouragement or support for teacher-led initiatives.

"We're told to be innovative, but there's no time set aside for planning or trying new things." — Teacher C, interview.

"Some of my students still don't have devices at home. That changes what I can do in class." — Teacher I, focus group.

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These systemic barriers contributed to a pervasive sense of professional isolation, especially among teachers in under resourced contexts. Several teachers also expressed a reluctance to take pedagogical risks due to unclear support from leadership.

"If I try something new and it doesn't go well, I worry it'll reflect poorly. It feels safer to stick with what's expected." — Teacher K, journal entry.

These findings point to a critical need for institutional reforms that support innovation not just rhetorically, but structurally by recognizing the time, trust, and infrastructure that meaningful change requires.

Interconnected Needs and Opportunities

The four themes identified—pedagogical, technological, professional and systemic are deeply intertwined. For example, teachers' limited TPACK enactment was not solely a technical issue but was shaped by broader challenges: lack of time to collaborate, limited access to meaningful PD and minimal institutional recognition of teacher-led innovation.

The initial findings of this study reveal significant insights into enhanced pedagogical practices, the development of contextually relevant teaching materials and the dynamics of collaboration. In relation to pedagogical practices (RQ1), teachers reported increased confidence in integrating digital tools to support inquiry-based learning, demonstrating the applicability of the TPACK framework (Mishra & Koehler, 2006). Many participants shifted toward more student-centered, inquiry-driven teaching approaches, incorporating strategies such as questioning, hypothesizing, and data analysis. Reflective journals and focus group discussions further highlighted the positive impact of the Lesson Study process in fostering reflective practices and shared professional learning among teachers.

Regarding the development of teaching materials (RQ2), the co-developed materials were found to be highly usable and contextually relevant, aligning with inquiry-based principles, technological tools, and curriculum objectives. The iterative refinement process allowed teachers to collaboratively adapt and enhance the materials, ensuring they were practical and suited to the diverse needs of their classroom contexts.

In the context of collaboration (RQ3), participants identified both challenges and opportunities. Key challenges included time constraints, differences in technological expertise and disparities in infrastructure, which often hindered seamless collaboration. Despite these obstacles teachers highlighted several opportunities, including professional growth, a sense of shared ownership over co-developed materials and improved confidence in collaborative practices facilitated through the Lesson Study process.

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Table 1: Interconnected Needs and Opportunities

Domain	Key Needs Identified	Implications for Interventions
Pedagogical	Lack of inquiry scaffolding, over-reliance on lecture, assessment pressures	Co-design structured inquiry lessons within Lesson Study
Technological	Tool use without strategy, poor alignment with inquiry, lack of multimedia design knowledge	Introduce TPACK-CTML-aligned PD; develop tool selection and design rubrics
Professional learning	Fragmented, top-down PD; limited time for reflection	Sustain peer-based, iterative cycles of collaborative planning and feedback
Systematic/ Institutional	No protected planning time, curriculum rigidity, tech inequity, low leadership support	Advocate for collaborative time, access equity, and recognition of teacher agency

Conclusion

This study presents a comprehensive diagnosis of the pedagogical, technological, professional and systemic needs experienced by secondary science teachers seeking to implement technology-integrated, inquiry-based instruction. Grounded in a Critical Participatory Action Research (CPAR) framework and informed by the TPACK model, Sociocultural Theory, and the Cognitive Theory of Multimedia Learning (CTML), the research surfaces layered and interconnected barriers that inhibit meaningful instructional transformation.

The findings reveal that while teachers are philosophically aligned with the principles of inquiry-based science education, they often lack the scaffolding strategies, assessment tools, and instructional confidence to enact it effectively. Similarly, although digital resources are present, their integration is frequently superficial and unaligned with inquiry goals reflecting gaps in both TPACK enactment and understanding of multimedia design principles grounded in CTML. Many teachers struggled to align technology use with cognitive learning processes, often inadvertently increasing cognitive load or limiting student agency.

Moreover, professional development opportunities have been experienced as fragmented, top-down, and decontextualized, limiting teachers' ability to experiment, reflect and grow in collaborative environments. These pedagogical and technological needs are compounded by systemic constraints such as rigid curricular pacing, limited planning time, infrastructure disparities, and inconsistent institutional support. The findings make clear that needs analysis cannot be separated from systemic reflection. Addressing the gaps identified in this study requires not only capacity building at the level of individual teacher knowledge and practice, but also the cultivation of school-wide structures that support collaborative inquiry, distributed leadership, and professional agency. As such, the study affirms the value of participatory, school embedded models like Lesson Study within CPAR as both a diagnostic and transformative strategy for educational improvement.

Building upon these insights, the next phase of this work should prioritize the co-design and implementation of targeted professional learning that directly addresses the identified needs particularly in scaffolding inquiry-based pedagogy, aligning technology use with cognitive design principles and fostering teacher-led innovation. Future research may examine the long-

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term effects of such interventions on student learning, teacher identity, and institutional culture. In parallel, educational leaders must advocate for structural conditions such as protected time, equitable access to digital tools, and recognition of teacher agency that sustain reflective, collaborative pedagogical development. Ultimately, this study positions needs analysis not as an end point but as a generative process that informs meaningful, systemic, and sustained transformation in science education.

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Conflicts of Interest
The author(s) reported no conflicts of interest.

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