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Exploring the Lived Experiences of Online Science Teachers in Using Virtual Laboratories for Instruction

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Abstract

This phenomenological study explored the lived experiences of certified online science teachers implementing virtual laboratories in fully online public-school settings across selected states in the United States. Guided by Constructivist Learning Theory, the Community of Inquiry (CoI) Framework, and the Technological Pedagogical Content Knowledge (TPACK) Framework, the study examined how teachers experienced and made meaning of virtual laboratory implementation, the challenges they encountered, and the instructional decisions and adaptations they employed. Using a qualitative phenomenological approach, data were gathered through semi-structured interviews and reflective written responses from seven certified online science teachers teaching Grades 4–12 in fully online public schools. The data were analyzed using Colaizzi's (1978) phenomenological method, with NVivo supporting data organization and coding through the extraction of significant statements, formulation of meanings, identification of emergent themes, and description of the essence of the phenomenon. The findings showed that participants viewed virtual laboratory implementation as an intentional, inquiry-oriented instructional process characterized by purposeful planning, guided facilitation, scientific exploration, and reflective practice. They also described challenges related to technological access, student engagement, conceptual misunderstandings, instructional adjustments, and institutional support. In response, participants employed learner-centered instructional decisions through responsive facilitation, differentiated support, continuous reflection, and assessment-informed adjustments. The findings suggest that meaningful virtual laboratory instruction extends beyond digital simulations and depends on intentional planning, responsive teaching, inquiry-based learning, and ongoing instructional adaptation. Based on these findings, a proposed instructional guide for implementing virtual laboratories in fully online science instruction was developed. The study highlights the importance of research-informed instructional guidance and institutional support in strengthening virtual laboratory implementation in online science education.

Keywords: *virtual laboratories, certified online science teachers, phenomenological study, fully online science instruction, lived experiences, meaning-making, TPACK, Community of Inquiry, constructivism*

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CHAPTER 1

THE PROBLEM AND ITS BACKGROUND

Introduction

Laboratory experiences have long been recognized as a fundamental component of science education because they allow learners to investigate scientific phenomena, test ideas through inquiry and experimentation, and apply scientific concepts in meaningful contexts. Through these experiences, students ask questions, analyze evidence, manipulate variables, and develop explanations based on their observations. Replicating these authentic laboratory experiences, however, remains one of the greatest challenges in fully online learning environments, where access to physical laboratory facilities is often unavailable.

One response to this challenge has been the increasing use of virtual laboratories (VLs) in online science instruction. These computer-based simulations enable learners to conduct experiments, manipulate variables, and visualize scientific processes in digital environments. Studies have shown that, when integrated purposefully into instruction, virtual laboratories promote scientific inquiry, concept exploration, and independent learning (Sapriati et al., 2023; Navarro et al., 2024). Their effectiveness, however, depends not only on the technology itself but also on teachers' instructional decisions, the level of technological Support available, and students' access to reliable digital resources.

The continued expansion of online education in the United States has further increased the need for effective virtual science instruction. Ongoing shortages of certified science teachers have prompted many schools and districts to rely on fully online instructional models that serve students across multiple locations. The National Center for Education Statistics (2024) continues to identify science and other STEM disciplines as areas affected by teacher shortages. Within these settings, virtual laboratories have become an important means of providing inquiry-based science experiences when traditional laboratory instruction is not feasible.

Despite growing interest in virtual laboratories, much of the existing research has focused on student achievement, learner perceptions, preservice teacher preparation, or implementation in blended and hybrid learning environments. Koca et al. (2024) similarly noted that quantitative and experimental studies continue to dominate this area of research, leaving comparatively little attention to teachers' own experiences. As a result, limited evidence explains how certified online science teachers working exclusively in fully online public-school settings implement virtual laboratories, respond to instructional and technological challenges, adapt their teaching practices, and make sense of those experiences.

Examining these lived experiences provides a richer understanding of virtual laboratory instruction beyond the technology itself. It offers insight into how teachers make instructional decisions, adjust their practices, and interpret their experiences as they facilitate science learning in fully online environments. Such understanding can inform future instructional practice, professional learning initiatives, and the continued development of virtual laboratory instruction in public-school settings.

Accordingly, this phenomenological study explored the lived experiences of certified online science teachers who implemented virtual laboratories in fully online public-school settings across selected U.S. states. Specifically, it examined how teachers described their experiences, the challenges they encountered, and the instructional decisions and adaptations they made throughout implementation. The findings aim to deepen understanding of virtual laboratory instruction while providing a foundation for future research and instructional improvement in online science education.

Theoretical Lens

This study is grounded primarily in a phenomenological perspective, which seeks to understand how individuals interpret and assign meaning to their lived experiences. Rather than viewing experiences as isolated events, phenomenology emphasizes how people perceive, reflect upon, and make sense of those experiences within their everyday lives. In this study, the implementation of virtual laboratories is examined through the lived experiences of certified online science teachers, focusing on how they describe, interpret, and make meaning of teaching science in fully online public-school settings. This perspective serves as the overarching lens for understanding the realities of virtual laboratory implementation from the teachers' own viewpoints.

The study is further informed by Constructivist Learning Theory, which views learning as an active process in which individuals construct knowledge through experience and interaction with their environment (Piaget, 1972). Within virtual laboratory instruction, this perspective explains how learners build scientific understanding by exploring concepts, investigating questions, and engaging in inquiry, even in the absence of physical laboratory facilities. It also provides a foundation for understanding how teachers design learning experiences that encourage students to actively construct scientific knowledge in online environments.

Complementing this perspective is the Community of Inquiry (CoI) Framework, which proposes that meaningful online learning develops through the interaction of teaching presence, cognitive presence, and social presence (Garrison et al., 2000). In the context of virtual laboratories, teaching presence is reflected in how teachers organize and facilitate laboratory activities, cognitive presence emerges as students investigate scientific ideas and develop explanations, and social presence is demonstrated through communication and collaboration during online learning. Together, these elements help explain how teachers foster engagement and meaningful learning while facilitating science instruction in virtual settings.

The study is also informed by the Technological Pedagogical Content Knowledge (TPACK) Framework, which emphasizes the integration of technological, pedagogical, and content knowledge required for effective teaching (Mishra & Koehler, 2006). Rather than treating technology as an independent instructional tool, the framework emphasizes balancing technological knowledge with sound pedagogy and strong content expertise. In implementing virtual laboratories, teachers draw upon these interconnected forms of knowledge to select appropriate digital tools, design inquiry-based learning experiences, and adapt instruction to meet students' learning needs in fully online environments.

Taken together, phenomenology serves as the primary lens for understanding teachers' lived experiences, while Constructivist Learning Theory, the Community of Inquiry Framework, and the TPACK Framework provide complementary perspectives for interpreting how inquiry-based learning, online interaction, and technology integration shape those experiences. Collectively, these frameworks explain how teachers make instructional decisions, integrate technology, pedagogy, and science content, and adapt their practices to the instructional and contextual demands of fully online science education. Guided by these complementary perspectives, the present study examined how certified online science teachers implemented virtual laboratories, navigated instructional and technological challenges, adapted their teaching practices, and made meaning of their experiences in fully online public-school settings.

Statement of the Problem

This phenomenological study aims to explore how certified online science teachers experience and make meaning of implementing virtual laboratories for instruction in fully online public-school settings across selected states in the United States.

Specifically, this study seeks to answer the following questions:

1. How do certified online science teachers describe their experiences and the meanings they derive from implementing virtual laboratories in science instruction?
2. What challenges do certified online science teachers encounter in implementing virtual laboratories in fully online science instruction?
3. How do certified online science teachers make instructional decisions and adapt their teaching practices during the implementation of virtual laboratories?
4. What instructional guide for virtual laboratory instruction can be developed from the themes and findings of the study?

Scope and Delimitation of the Study

This phenomenological study was conducted during the first semester of School Year 2025–2026 to explore the lived experiences of certified online science teachers who implement virtual laboratories in fully online public-school settings. The co-participants consisted of seven certified online science teachers teaching Grades 4–12 science courses in virtual public and charter schools across selected states in the United States. They taught subjects including General Science, Biology, Environmental Science, Chemistry, Physics, Physical Science, Anatomy, and Physiology through synchronous and asynchronous instruction. The inquiry examined how participants experienced the implementation of virtual laboratories, the challenges they encountered, and the instructional decisions and adaptations they employed to facilitate online science learning.

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The inquiry was limited to the perspectives of certified online science teachers and did not include those of students, parents, school administrators, teaching assistants, or other educational stakeholders. Data were obtained through reflective written responses and follow-up semi-structured interviews. Quantitative measures, student achievement data, statistical analyses, and classroom observations were beyond the scope of this investigation. In addition, the study focused exclusively on computer-based virtual laboratory simulations used in fully online science instruction and excluded physical laboratory activities, blended or hybrid learning environments, augmented reality, virtual reality, and other immersive instructional technologies.

The findings reflect the co-participants' experiences within their respective instructional contexts during the data collection period. Consistent with the phenomenological research design, the study does not seek to generalize these findings to all online science teachers; rather, it provides an in-depth understanding of the phenomenon as experienced and interpreted by the participants. The findings also informed the development of a proposed instructional guide for implementing virtual laboratories in fully online science instruction and may serve as a resource for instructional practice, professional learning, and future qualitative research in online science education.

Significance of the Study

This study contributes to a richer understanding of how certified online science teachers experience and make meaning of the implementation of virtual laboratories in fully online learning environments. By examining their experiences, instructional adaptations, challenges, and reflections, the findings offer practical and scholarly insights that may benefit the following stakeholders.

Online Science Teachers. The findings encourage teachers to reflect on their instructional practices and offer perspectives on the implementation of virtual laboratories in fully online science instruction. The experiences shared by the co-participants highlight effective instructional approaches, common challenges, and practical strategies that may strengthen the facilitation of virtual laboratory activities.

Science Educators and Classroom Teachers. The study broadens understanding of how technology-mediated science instruction can Support inquiry, student engagement, and conceptual learning. These insights may help educators consider ways of integrating virtual laboratories into science teaching across different instructional contexts.

School Administrators and Educational Leaders. The findings provide a clearer picture of the instructional realities experienced by online science teachers and the support needed for successful implementation of virtual laboratories. This understanding can inform decisions related to professional learning, instructional resources, and the continued improvement of online science programs.

Curriculum Developers and Instructional Designers. The experiences documented in this study offer practical guidance for designing curriculum materials, instructional resources, and

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learning experiences that better address the realities of implementing virtual laboratories in fully online science education.

Educational Technology Developers. The findings identify instructional needs and challenges teachers encounter when using virtual laboratories. These insights may support the continued refinement of virtual laboratory platforms and other educational technologies to better align with classroom practice.

Researchers and Future Scholars. This study adds to the growing body of qualitative research on virtual laboratories and online science instruction. It also provides a foundation for future studies that examine teachers' lived experiences, instructional decision-making, and technology integration across different educational settings.

The findings may also serve as a reference for future studies that seek to further explore the experiences of teachers and other stakeholders in technology-mediated science learning environments.

Students. Although students were not direct participants in the study, they may benefit indirectly from instructional practices and learning experiences informed by a deeper understanding of how virtual laboratories can be meaningfully implemented to support inquiry, engagement, and conceptual understanding in online science education.

Definition of Terms

Certified Online Science Teachers. In this study, these refer to the seven licensed or certified science educators teaching Grades 4–12 science subjects in fully online public and charter school programs across selected states in the United States who participated as co-participants in the study.

Fully Online Public-School Settings. In this study, fully online public-school settings refer to accredited public-school educational environments in which science instruction, learning activities, communication, and assessment are delivered entirely through digital platforms and learning Management systems without face-to-face classroom interaction. These settings serve students in Grades 4–12 and rely on virtual technologies, including virtual laboratories, as essential instructional resources for science teaching and learning.

Implementation of Virtual Laboratories. In this study, implementation of virtual laboratories refers to the planning, facilitation, integration, and utilization of virtual laboratory activities by certified online science teachers as part of their instructional practices in fully online science learning environments.

Inquiry-Based Instruction. In this study, inquiry-based instruction refers to the instructional approaches described by the co-participants that engage students in questioning, investigation, exploration, and the construction of scientific explanations through virtual laboratory activities.

Instructional Adaptations. In this study, instructional adaptations refer to the adjustments, modifications, and responsive strategies employed by certified online science teachers to address instructional demands, student needs, and contextual challenges during the implementation of virtual laboratories.

Lived Experiences. In this study, lived experiences refer to the experiences, challenges, instructional adaptations, reflections, and meanings described by certified online science teachers regarding their implementation of virtual laboratories in fully online science instruction.

Meaning-Making. In this study, meaning-making refers to the interpretations, insights, realizations, and professional understandings that certified online science teachers derive from their experiences of implementing virtual laboratories.

Proposed Instructional Guide. In this study, the proposed instructional guide refers to the researcher-developed guide, derived from the study's themes and findings, that provides insights and recommendations for implementing virtual laboratories in fully online science instruction.

Virtual Laboratories (VLs). In this study, virtual laboratories refer to computer-based laboratory simulations and digital science applications used by certified online science teachers to facilitate scientific investigations, concept exploration, and inquiry-based activities in fully online science instruction.

Chapter 2
REVIEW OF RELATED LITERATURE AND STUDIES

This chapter presents a review of the literature and empirical studies relevant to the implementation of virtual laboratories in fully online science instruction. It examines literature on the role of laboratory experiences in science education, the emergence and application of virtual laboratories, and the instructional realities of teaching science in fully online learning environments. The chapter also reviews studies that discuss the use of virtual laboratories to support inquiry, concept exploration, and independent learning, as well as the technological, pedagogical, and accessibility considerations associated with their implementation.

The reviewed literature provides a comprehensive understanding of the current state of knowledge on virtual laboratory implementation while identifying areas that remain underexplored. Specifically, it highlights the limited attention paid to the lived experiences, instructional decision-making, challenges, and meaning-making of certified online science teachers working in fully online public school settings. Collectively, the reviewed literature provides the foundation for this study by identifying the research gap and demonstrating the need to further examine the implementation of virtual laboratories in fully online science education.

Laboratory Activities and Inquiry-Based Science Learning

Laboratory activities are widely recognized as a fundamental component of science education because they allow learners to investigate scientific concepts through direct experience. Rather than simply acquiring scientific knowledge, students actively explore phenomena, gather and analyze evidence, and develop explanations based on their observations. Contemporary science education emphasizes that laboratory experiences are most meaningful when learners engage in authentic scientific practices that promote conceptual understanding rather than relying solely on memorizing scientific facts (National Research Council, 2022).

This emphasis on active learning is closely aligned with inquiry-based science instruction, which encourages learners to ask questions, test ideas, analyze evidence, and draw conclusions through investigation. Laboratory activities provide opportunities for these inquiry processes by allowing students to manipulate variables, observe outcomes, and examine relationships among scientific concepts. Supasorn and Promarak (2023) reported that inquiry-oriented laboratory experiences strengthen scientific reasoning and promote higher-order thinking by encouraging investigation, reflection, and evidence-based decision-making.

Beyond supporting conceptual learning, laboratory experiences also foster the development of essential scientific process skills. Through experimental investigations, learners practice observing, predicting, interpreting data, communicating findings, and solving problems, all of which contribute to scientific literacy and prepare them to apply scientific knowledge in a variety of contexts. Navarro et al. (2024) emphasized that laboratory experiences provide opportunities for learners to investigate scientific phenomena, engage in collaborative inquiry, and construct scientific understanding through exploration and experimentation. These experiences also help learners connect abstract scientific concepts with observable phenomena and real-world situations, making science learning more meaningful and relevant. By linking theory with practice, laboratory activities promote deeper conceptual understanding and encourage students to apply scientific knowledge beyond the classroom.

Recent studies further indicate that active participation in inquiry-based laboratory experiences enhances learner engagement and encourages greater ownership of learning. Sapriati et al. (2023) reported that laboratory investigations foster independent learning by actively involving students in scientific exploration. Likewise, Grammens et al. (2024) found that inquiry-oriented laboratory experiences encourage learners to analyze evidence, reflect on observations, and refine their understanding through iterative investigation. Together, these studies reinforce the value of laboratory experiences in strengthening scientific reasoning and supporting inquiry-based learning.

Overall, the reviewed literature consistently identifies laboratory activities as a cornerstone of science education because they promote inquiry, critical thinking, and conceptual understanding through active participation. The literature further suggests that meaningful science learning occurs when students engage directly in scientific practices rather than passively receiving information. These findings underscore the importance of identifying effective ways to sustain inquiry-based instruction in fully online settings, where access to traditional laboratory experiences is often limited. Within this context, exploring how certified online science teachers

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implement virtual laboratories and make meaning of these experiences addresses an important gap in contemporary science education research.

Virtual Laboratories in K–12 Science Education

Virtual laboratories have become an increasingly important component of K–12 science education as schools continue to expand the use of technology-enhanced and online learning. These computer-based simulations enable learners to conduct experiments, manipulate variables, visualize scientific processes, and investigate scientific phenomena within digital environments. As a result, virtual laboratories are now used across elementary, middle school, and high school science to supplement or, when necessary, replace traditional laboratory experiences, particularly in settings with limited access to laboratory facilities and equipment.

In elementary science education, virtual laboratories introduce young learners to foundational scientific concepts through interactive and visually engaging activities. Sapriati et al. (2023) reported that these experiences encourage students to observe scientific phenomena, explore cause-and-effect relationships, and develop curiosity through guided inquiry. Interactive features such as manipulating digital objects, making predictions, and observing outcomes help strengthen conceptual understanding while maintaining active participation in science learning.

At the middle school level, virtual laboratories support inquiry-based investigations, allowing students to explore scientific ideas that may be difficult to demonstrate through traditional classroom instruction. Navarro et al. (2024) found that virtual laboratory simulations provide opportunities for learners to investigate scientific relationships, conduct experiments, and engage in interactive exploration. Similarly, Grammens et al. (2024) observed that these experiences encourage students to analyze evidence, interpret observations, and participate more actively in scientific inquiry.

In high school science, virtual laboratories are frequently used to support more advanced investigations and the exploration of complex scientific concepts. Koca et al. (2024) explained that virtual laboratory simulations enable students to manipulate experimental conditions and visualize scientific processes that may be difficult, costly, or unsafe to conduct in traditional laboratory settings. Likewise, Alqallaf (2025) emphasized that these digital environments strengthen inquiry, experimentation, analytical thinking, and problem-solving through interactive learning experiences.

The expanding use of virtual laboratories across K–12 education also reflects the broader integration of educational technologies and online instruction. Recent studies indicate that these tools are now used across multiple science disciplines to support investigation, experimentation, and concept development in digital learning environments. Their successful implementation, however, depends on several contextual factors, including technological accessibility, instructional support, teacher Preparedness, and the extent to which virtual laboratory activities are meaningfully integrated into science instruction.

Overall, the reviewed literature demonstrates that virtual laboratories have become valuable instructional resources across all levels of K–12 science education. Although their applications differ according to students' developmental needs, the studies consistently show that virtual laboratories support inquiry, scientific investigation, and conceptual learning through interactive digital experiences. These findings provide important context for the present study, as certified online science teachers frequently depend on virtual laboratories to facilitate science instruction in fully online environments where traditional laboratory experiences are not readily available. Examining how these teachers implement virtual laboratories and make meaning of those experiences, therefore, addresses an important area of inquiry in contemporary science education.

Virtual Laboratories in Fully Online Learning Environments

The increasing adoption of fully online learning environments has transformed the delivery of science instruction and intensified the need for alternative approaches to laboratory learning. Fully online learning environments are educational settings in which teaching and learning occur entirely through digital platforms without face-to-face classroom interaction. In these environments, science teachers frequently rely on technology-mediated instructional resources to provide opportunities for scientific inquiry, experimentation, and concept exploration despite the absence of physical laboratory facilities.

Virtual laboratories have emerged as important instructional resources in fully online science education because they enable learners to conduct investigations, manipulate variables, observe scientific processes, and engage in interactive learning experiences within digital environments. According to Navarro et al. (2024), virtual laboratory simulations provide learners with opportunities to investigate scientific phenomena and participate in inquiry-oriented activities that may otherwise be difficult to facilitate in fully online settings. Their interactive features allow learners to explore scientific concepts through experimentation and observation while participating in science learning remotely.

As emphasized by Koca et al. (2024), virtual laboratories have increasingly been integrated into fully online science instruction because they provide flexible and accessible opportunities for scientific investigations that are not constrained by location or the availability of physical laboratory resources. Similarly, Sapriati et al. (2023) noted that virtual laboratories support independent exploration and allow learners to engage in scientific activities at their own pace within online learning environments. These characteristics have contributed to the growing utilization of virtual laboratories in fully online science programs and virtual schools.

The implementation of virtual laboratories in fully online learning environments also requires teachers to make instructional decisions regarding lesson organization, facilitation of inquiry activities, student engagement, and the provision of instructional support. Grammens et al. (2024) highlighted that meaningful online laboratory experiences require intentional instructional design and guided facilitation to support learners' participation and conceptual exploration. Likewise, Alqallaf (2025) emphasized that the successful integration of virtual laboratories in online environments depends not only on the availability of digital technologies but also on teachers' abilities to organize learning experiences and respond to students' instructional needs.

Recent literature further suggests that fully online science instruction presents unique instructional realities that differ from blended and hybrid learning environments. In fully online settings, virtual laboratories often serve as the primary means of providing laboratory experiences because students lack access to face-to-face laboratory sessions. Consequently, science teachers assume important roles in designing, facilitating, and adapting virtual laboratory experiences that support scientific inquiry and participation within entirely digital instructional contexts.

Taken together, the reviewed literature suggests that virtual laboratories have become essential instructional resources in fully online science learning environments because they provide opportunities for scientific investigation, experimentation, and inquiry in the absence of physical laboratory facilities. The studies consistently indicate that implementing virtual laboratories in fully online settings entails more than using digital simulations and requires intentional instructional planning and facilitation within technology-mediated environments.

Teachers' Roles in Facilitating Virtual Laboratory Activities

Teachers play a central role in ensuring that virtual laboratory activities promote meaningful learning rather than simply providing access to digital simulations. Effective implementation requires purposeful instructional planning, guidance, and continuous support that encourage scientific inquiry, sustain student engagement, and help learners develop conceptual understanding. As Alqallaf (2025) emphasized, teachers serve as facilitators who intentionally design learning experiences and guide students through scientific investigations in technology-mediated environments.

One important instructional responsibility is modeling. Teachers demonstrate how virtual laboratory tools operate, explain scientific procedures, and model appropriate approaches to conducting investigations and interpreting results. Navarro et al. (2024) reported that teacher modeling helps students become familiar with digital laboratory tools, builds confidence in completing investigations, and clarifies expectations for scientific tasks.

Teachers also facilitate learning through purposeful questioning. Carefully designed questions encourage students to make predictions, justify explanations, analyze evidence, and reflect on the results of their investigations. Grammens et al. (2024) found that questioning strengthens inquiry by promoting evidence-based reasoning while helping learners connect prior knowledge with new scientific experiences.

Another essential responsibility is providing scaffolding and differentiated support. Teachers simplify instructions, when necessary, offer guiding prompts and additional explanations, and gradually release responsibility as students become more confident in conducting investigations independently. Sapriati et al. (2023) noted that these instructional supports help learners navigate scientific tasks and remain actively engaged in inquiry-based learning, particularly in virtual environments where immediate face-to-face assistance is unavailable.

Teachers further support learning by monitoring student progress and providing timely feedback. Continuous observation allows teachers to identify misconceptions, clarify misunderstandings, and adjust instruction in response to students' evolving needs. Koca et al. (2024) emphasized that responsive feedback is essential for maintaining engagement and helping students make sense of scientific experiences within digital environments.

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Assessment is equally important in virtual laboratory instruction. Rather than focusing solely on correct answers, effective assessment examines students' observations, scientific explanations, reflections, and use of evidence throughout the learning process. Grammens et al. (2024) suggested that these assessment practices provide meaningful insight into students' scientific thinking while supporting continued inquiry and conceptual development.

Overall, the reviewed literature portrays teachers as active facilitators whose responsibilities extend beyond the mere operation of digital technologies. Through modeling, questioning, scaffolding, feedback, monitoring, and assessment, teachers create the conditions necessary for meaningful inquiry-based learning in virtual laboratory environments. These findings provide important context for the present study by highlighting the instructional responsibilities that certified online science teachers perform while implementing virtual laboratories in fully online settings.

Challenges in Virtual Laboratory Implementation

Despite the increasing integration of virtual laboratories into science education, their implementation continues to present instructional and technological challenges. Because virtual laboratory activities depend heavily on digital technologies, reliable internet access, and active student participation, their effectiveness is influenced by a range of contextual factors that affect both teaching and learning in online environments.

One of the most commonly reported challenges is access to technology and technical reliability. Successful participation requires stable internet connectivity, functional devices, and dependable access to digital platforms and simulations. Koca et al. (2024) identified unstable internet connections, device incompatibility, and limited access to digital resources as persistent barriers to the implementation of virtual laboratories. Likewise, Shambare and Jita (2025) found that technological disruptions frequently interrupt instruction and limit students' participation in online science activities.

Another challenge involves maintaining student engagement and participation. Unlike face-to-face classrooms, fully online environments often make it more difficult to sustain attention, encourage active involvement, and support meaningful participation during laboratory investigations. Grammens et al. (2024) noted that students demonstrate varying levels of engagement in virtual learning environments and frequently require additional guidance to remain actively involved in inquiry-based activities. Differences in participation may also reduce opportunities for collaboration and scientific discussion.

Conceptual understanding presents another area of concern. Because students often interpret simulation results independently, misconceptions may develop when scientific concepts are not sufficiently explained or supported. Navarro et al. (2024) emphasized that instructional guidance and opportunities for reflection are essential to helping learners accurately interpret observations and build sound conceptual understanding.

Teachers also face challenges in managing instructional pacing. Students complete virtual laboratory activities at different rates, requiring teachers to balance lesson progress with individual learning needs. Sapriati et al. (2023) reported that variations in pacing can complicate the facilitation of inquiry-based learning and require responsive instructional adjustments to ensure that all students remain engaged throughout the investigation.

In addition, academic integrity and student independence remain important considerations in fully online science instruction. Because teachers cannot directly observe students throughout virtual laboratory activities, they rely more heavily on students' self-regulation and responsible participation. Alqallaf (2025) highlighted that online learning requires students to manage tasks independently while demonstrating honesty and accountability, making authentic participation an ongoing instructional concern.

Overall, the reviewed literature demonstrates that implementing virtual laboratories involves challenges extending beyond technology itself. Issues related to technological access, student engagement, conceptual understanding, pacing, and academic integrity require teachers to make continuous instructional decisions as they adapt to the realities of fully online learning environments. These findings provide important context for the present study by highlighting the complexities that certified online science teachers navigate when implementing virtual laboratories and underscore the need to understand how they experience and make meaning of these challenges.

Emerging Gaps in Virtual Laboratory Research

The growing body of literature underscores the growing importance of virtual laboratories in science education, particularly in supporting inquiry, conceptual understanding, learner engagement, and scientific reasoning. Although recent studies have examined student achievement, perceptions of virtual simulations, conceptual learning, and comparisons between virtual and traditional laboratory experiences, much of this research has relied on quantitative and experimental designs. Koca et al. (2024) noted that existing studies continue to emphasize learning outcomes and instructional effectiveness, while Navarro et al. (2024) observed that comparatively little attention has been given to teachers' instructional experiences and how they make meaning of implementing virtual laboratories.

Existing research has also examined the use of virtual laboratories in blended, hybrid, and other technology-enhanced learning environments. Grammens et al. (2024) reported that these studies commonly focus on the effectiveness of digital simulations, learner engagement, and the impact of technology on science achievement. Similarly, Sapriati et al. (2023) observed that recent investigations have primarily emphasized student outcomes and the pedagogical potential of virtual laboratory technologies. While these studies provide valuable evidence on the educational benefits of virtual laboratories, they offer comparatively limited insight into teachers' experiences implementing these technologies in fully online instructional contexts.

Moreover, relatively few studies have examined the experiences of certified online science teachers working exclusively in fully online public school settings, where virtual laboratories often replace traditional laboratory activities. As a result, limited attention has been given to how these educators facilitate virtual laboratory instruction, respond to instructional and technological challenges, make instructional decisions, adapt their teaching practices, and interpret these experiences in their professional work. Consequently, the perspectives of teachers who regularly implement virtual laboratories in fully online science classrooms remain underrepresented in the existing literature.

Collectively, the reviewed literature highlights the need for qualitative inquiry that moves beyond evaluating student outcomes and instructional effectiveness to better understand the human dimensions of virtual laboratory implementation. Such understanding is important because implementing virtual laboratories involves more than using digital technologies; it also requires teachers to reflect on their experiences, adapt instruction to changing contexts, and make informed decisions that support student learning. Guided by this identified gap, the present phenomenological study explores how certified online science teachers experience and make meaning of implementing virtual laboratories in fully online public-school settings across selected states in the United States.

Professional Development and Instructional Adaptation in Online Science Teaching

The increasing integration of digital technologies in education has expanded the instructional responsibilities of online science teachers and highlighted the importance of continuous professional development and instructional adaptation. Teaching science in fully online environments requires competencies that extend beyond content knowledge to include technological proficiency, pedagogical flexibility, and the ability to respond to changing instructional contexts. Talafian et al. (2023) emphasized that effective online science instruction depends on continuous professional learning that strengthens teachers' instructional strategies and technological skills for facilitating meaningful learning in digital environments.

Professional development supports teachers in implementing technology-enhanced instruction while responding to evolving educational demands. Tikly (2024) explained that meaningful professional learning strengthens instructional decision-making and helps teachers develop practices that are responsive to diverse learners and changing educational contexts. Likewise, Santoro et al. (2023) found that ongoing professional development enhances teachers' confidence in using digital technologies while strengthening their ability to facilitate inquiry-based learning and student engagement.

Equally important is instructional adaptation, as fully online science teaching often requires teachers to adjust their practices in response to students' needs and the realities of digital learning. These adjustments may include modifying activities, providing differentiated support, revising instructional approaches, and offering additional guidance throughout the learning process. Liu (2024) described instructional adaptation as a reflective decision-making process through which teachers continuously evaluate learning situations and modify instruction to promote meaningful participation and conceptual understanding. Similarly, Lopez-Miranda et al. (2025) emphasized that effective online teaching requires flexibility in responding to learners' needs, technological conditions, and changing classroom circumstances.

Reflection is closely connected to this process of adaptation. By evaluating the effectiveness of their instructional decisions and examining challenges encountered during implementation, teachers identify opportunities to improve future practice. Rosales (2024) highlighted that reflective practice helps teachers become more responsive to learners' experiences while supporting continuous improvement in instructional planning and facilitation.

Through ongoing reflection, teachers refine their professional judgment and strengthen the instructional decisions that guide future teaching.

Overall, the reviewed literature demonstrates that professional development, instructional adaptation, and reflective practice are interconnected components of effective online science teaching. Together, they enable teachers to strengthen their professional competencies, respond to technological and pedagogical challenges, and continually refine their instructional approaches. These findings provide important context for the present study, as certified online science teachers who regularly implement virtual laboratories rely on these processes to support meaningful learning in fully online environments.

Synthesis

The reviewed literature consistently demonstrates that laboratory experiences remain central to science education and that virtual laboratories have become valuable instructional resources for supporting inquiry, conceptual understanding, and scientific investigation across K–12 settings. In fully online environments, where access to traditional laboratory experiences is limited, virtual laboratories offer meaningful opportunities for science learning when supported by thoughtful instructional design and effective facilitation.

Across the reviewed studies, successful implementation is consistently associated with purposeful instructional planning, active teacher facilitation, and ongoing support that sustain student engagement and inquiry. At the same time, the literature identifies recurring challenges related to access to technology, student participation, conceptual understanding, instructional pacing, and academic integrity. Addressing these challenges requires teachers to make continuous instructional decisions and adapt their practices to the changing demands of fully online science instruction.

Despite these contributions, existing research has focused predominantly on student outcomes, perceptions of virtual laboratories, and quantitative comparisons of instructional approaches across various educational settings. Comparatively little attention has been paid to the lived experiences of certified online science teachers who implement virtual laboratories in fully online public-school environments. This gap underscores the need for qualitative inquiry that explores how teachers experience virtual laboratory implementation, navigate instructional challenges, and make meaning of these experiences in practice. Comparatively little attention has been paid to the experiences of certified online science teachers working exclusively in fully online public-school settings. Consequently, there remains a limited understanding of how these educators implement virtual laboratories, navigate instructional and technological challenges, make instructional decisions, adapt their teaching practices, and interpret these experiences within their professional practice.

These gaps in the literature provided the foundation for the present phenomenological study. By exploring the experiences of certified online science teachers, this study sought to deepen understanding of virtual laboratory implementation in fully online public-school settings, including the challenges encountered, the instructional decisions and adaptations employed, and the meanings participants attributed to these experiences. In doing so, the study contributes to the growing body of knowledge on online science education and provides a research-informed

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foundation for strengthening the implementation of virtual laboratories in fully online learning environments.

Chapter 3

METHODOLOGY

This chapter presents the methodological procedures used in this phenomenological inquiry, including the research design, study locale, selection of co-participants, research instruments, data gathering procedures, data analysis, strategies for ensuring trustworthiness, and ethical considerations. Guided by a phenomenological approach, the inquiry explored the lived experiences of certified online science teachers implementing virtual laboratories in fully online learning environments. Data were collected through semi-structured online interviews conducted via Zoom and through reflective written responses submitted via email to obtain rich, detailed accounts of the co-participants' experiences. These complementary data sources provided the basis for understanding the essence of participants' experiences and the meanings they attributed to the implementation of virtual laboratories in their instructional contexts.

Research Design

This study employed a qualitative phenomenological research design to explore the lived experiences of certified online science teachers who implement virtual laboratories in fully online public-school settings. A phenomenological approach was appropriate because it enabled an in-depth examination of how participants experienced the implementation of virtual laboratories and the meanings they attributed to those experiences within their instructional contexts.

Phenomenological research seeks to describe and interpret individuals' lived experiences of a particular phenomenon. Creswell and Poth (2024) explained that phenomenology aims to understand the essence of human experience from the perspectives of individuals who have directly encountered the phenomenon under investigation. In the present inquiry, the phenomenon focused on the implementation of virtual laboratories in fully online science instruction, as experienced by certified online science teachers.

Rather than evaluating the effectiveness of virtual laboratories or measuring instructional outcomes, the inquiry focused on understanding participants' experiences of implementation, the challenges they encountered, the instructional decisions they made, and the adaptations they employed in their teaching practice. Data were gathered through semi-structured online interviews conducted via Zoom and reflective written responses submitted through email, allowing participants to describe their experiences in their own words and reflect on how they navigated the realities of facilitating virtual laboratories in fully online science instruction. As Moustakas (2023) emphasized, phenomenological inquiry seeks to understand experiences as they are lived and described by those who experience them, making this approach well-suited to the study's purpose.

This research design provided an in-depth understanding of the shared meanings embedded within participants' lived experiences of implementing virtual laboratories. It also offered insight into how they navigated instructional and contextual challenges, adapted their

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teaching practices, and made informed instructional decisions while facilitating science learning in fully online environments.

Research Locale

This study was conducted in accredited virtual public and charter school programs across selected states in the United States, specifically California, Tennessee, Florida, New Mexico, and New Jersey. These schools delivered Grades 4–12 science instruction through online learning platforms and learning Management systems, providing the context for examining virtual laboratory implementation in fully online educational settings.

The United States was selected as the research context because virtual public-school programs have become increasingly prominent in K–12 education in response to expanding online learning opportunities, teacher shortages, and the growing integration of digital technologies into instruction. Within these settings, virtual laboratories often serve as alternatives to physical laboratory experiences, making them an appropriate context for exploring how certified online science teachers implement and interpret their use in practice.

The selected states represented the locations of the co-participants' schools and provided access to certified online science teachers with direct experience implementing virtual laboratories. Participants were recruited through purposive sampling from virtual public and charter school programs across these states. The researcher had previously worked with and personally known the co-participants through professional teaching experiences, which facilitated access to information-rich participants who met the study's inclusion criteria. Including teachers from multiple states and educational contexts enriched the data by capturing varied yet comparable perspectives on virtual laboratory implementation.

Collectively, these research settings provided diverse instructional contexts in which virtual laboratories served as essential resources for science teaching when physical laboratory facilities were unavailable. Examining participants' experiences across these settings provided a rich understanding of the phenomenon and the meanings they attributed to the implementation of virtual laboratories in fully online science education.

Selection of Co-Participants

The participants in this study were certified online science teachers employed in fully online public-school programs in the United States who regularly incorporated virtual laboratories into their science instruction. Purposive sampling was used to recruit information-rich participants with direct experience with the phenomenon who could provide detailed accounts of implementing virtual laboratories in their instructional contexts.

Potential participants were identified through the researcher's professional network established during previous employment with Proximity Learning, Inc. This connection provided access to certified online science teachers with relevant experience in online science education. Eight teachers who met the preliminary qualifications were invited to participate through email. Invitation letters and informed consent forms were distributed electronically, and interested individuals were screened using the established inclusion criteria. Of the eight teachers invited, seven voluntarily agreed to participate, while one declined.

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To be eligible, participants were required to: (1) hold a valid science teaching license or certification; (2) currently teach Grades 4–12 science subjects in fully online public-school settings; (3) regularly implement virtual laboratories as part of science instruction; and (4) have at least one year of experience teaching science online. Eligibility was verified through signed informed consent forms and the researcher's professional knowledge that the participants were actively employed as online science teachers with Proximity Learning, Inc. during the data collection period.

The final sample consisted of seven certified online science teachers representing California, Tennessee, Florida, New Mexico, and New Jersey. They taught General Science, Biology, Chemistry, Physical Science, Environmental Science, Physics, Anatomy, and Physiology across a variety of online public-school programs. Including teachers from different science disciplines and educational contexts enriched the study by providing varied yet comparable perspectives on the phenomenon.

Teachers who were not employed in fully online public school settings, did not regularly implement virtual laboratories, or had less than 1 year of online science teaching experience were excluded. A sample of seven participants was appropriate for phenomenological inquiry because it allowed for an in-depth exploration of a shared lived experience. Creswell and Poth (2024) noted that phenomenological studies typically involve a small number of participants to facilitate rich descriptions of a common phenomenon. The narratives gathered from the participants provided sufficient depth to identify shared meanings and describe the essence of implementing virtual laboratories in online science instruction.

Research Instrument

The primary instruments used in this study were a researcher-developed reflective written response guide and a semi-structured interview guide consisting of seven (7) open-ended questions. These instruments were developed based on the Statement of the Problem and the theoretical perspectives underpinning the study to explore the lived experiences of certified online science teachers who implement virtual laboratories in fully online public-school settings. The questions were designed to elicit detailed narratives about participants' experiences, the challenges they encountered, the instructional decisions and adaptations they employed, and the meanings they attributed to the implementation of virtual laboratories.

The reflective written response guide served as the primary data collection instrument. Participants first responded to the seven open-ended questions through written narratives submitted via email, allowing sufficient time for thoughtful reflection before the interviews. The same guide was then used during synchronous Zoom interviews to clarify, verify, and expand upon the written responses. When appropriate, follow-up and probing questions were asked to encourage deeper reflection, clarify ambiguities, and obtain richer descriptions of participants' lived experiences.

The semi-structured interview format ensured consistency across participants while providing the flexibility to explore emerging ideas during each interview. This approach enabled participants to describe their experiences in their own words, explain significant events, discuss

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instructional decisions, and reflect on the meanings they associated with the implementation of virtual laboratories in online science instruction.

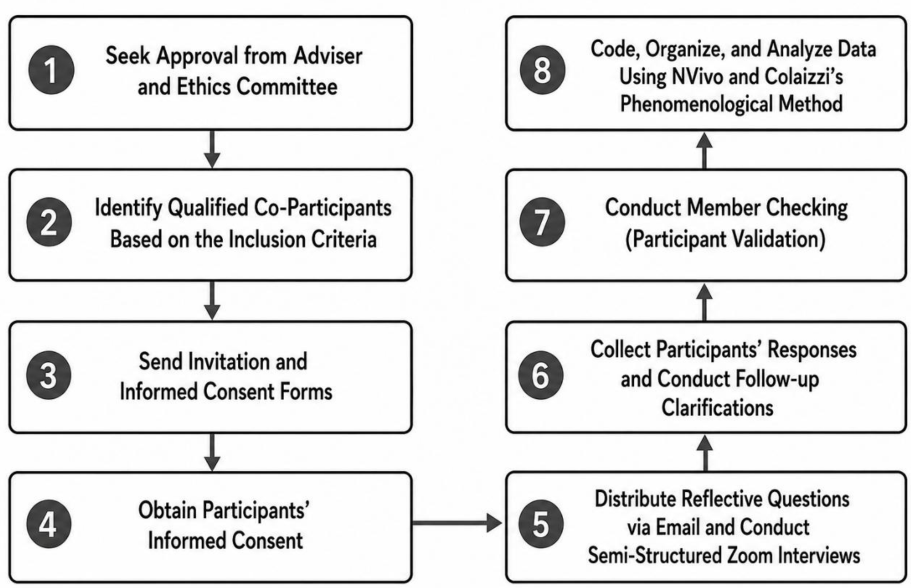
To establish the quality and appropriateness of the instruments, both the reflective written response guide and the semi-structured interview guide were submitted to three (3) experts in qualitative research, science education, and educational technology for content validation. The validators evaluated the instruments for clarity, relevance, alignment with the research questions, appropriateness of wording, and their capacity to elicit rich descriptions of the phenomenon. Their recommendations were incorporated to improve the wording, sequencing, and overall alignment of the questions with the study's purpose and theoretical perspectives.

The validated instruments generated rich narrative accounts that supported an in-depth understanding of how certified online science teachers implemented virtual laboratories, navigated instructional challenges, adapted their teaching practices, and interpreted the meanings of these experiences within fully online science instruction.

Data Gathering Procedure

Figure 1.

Systematic and Ethical Data Collection and Analysis Process for Exploring Certified Online Science Teachers' Lived Experiences in Implementing Virtual Laboratories



The data collection process employed a systematic, ethical, and phenomenological approach to explore the lived experiences of certified online science teachers who implement virtual laboratories in fully online public school settings. Figure 1 illustrates the sequence of the data collection and analysis procedures employed in the study. Data collection began after

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securing approval from the research adviser and the University Ethics Committee. Participants were then identified through purposive sampling based on the established inclusion criteria. Invitation letters and informed consent forms were distributed electronically, and only those who voluntarily agreed to participate were included in the study.

After informed consent was obtained, the researcher distributed the reflective written response guide via email through Google Forms, allowing participants sufficient time to provide thoughtful narrative responses to the seven open-ended questions. These written narratives served as the primary source of data. After reviewing the submitted responses, the researcher conducted semi-structured Zoom interviews to clarify and expand upon participants' written accounts. Follow-up and probing questions were used when appropriate to encourage deeper reflection, clarify ambiguities, and elicit richer descriptions of their experiences with the implementation of virtual laboratories.

Following data collection, member checking was conducted by returning the interpreted responses and preliminary findings to the participants for verification. This process enabled participants to confirm the accuracy of the interpretations and helped ensure that their experiences and intended meanings were faithfully represented.

Consistent with the phenomenological perspective described by Creswell and Poth (2024), the written narratives and Zoom interview transcripts were analyzed using Colaizzi's phenomenological method, with NVivo used to organize and code the qualitative data. NVivo facilitated the Management of significant statements, the formulation of meanings, the clustering of themes, and the identification of emergent themes. Guided by Colaizzi's method, the researcher repeatedly reviewed the narratives and interview transcripts, extracted significant statements, formulated meanings, organized them into thematic clusters, and synthesized an exhaustive description that captured the essence of participants' lived experiences implementing virtual laboratories in fully online science instruction.

Researcher's Reflexivity and Bracketing

Because the researcher had prior experience in science education, online teaching, and technology-mediated learning, it was important to acknowledge potential assumptions regarding the implementation and use of virtual laboratories in science instruction. Previous exposure to virtual laboratory simulations also suggested that personal experiences could influence participants' narrative interpretations.

To minimize this risk, bracketing was practiced throughout the study. Personal beliefs, expectations, and prior experiences related to virtual laboratories were consciously set aside to remain open to the meanings and perspectives shared by the participants.

Throughout data analysis, the researcher continually returned to the participants' narratives to ensure that interpretations remained grounded in their descriptions rather than in preconceived assumptions or theoretical expectations. Follow-up clarifications and member checking further strengthened the credibility of the findings by confirming that the interpretations accurately reflected participants' experiences and the meanings they attributed to the implementation of virtual laboratories in fully online science instruction.

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Data Analysis

This study employed Colaizzi's (1978) phenomenological method to analyze the lived experiences of certified online science teachers implementing virtual laboratories in fully online science instruction. This approach was selected because it offers a systematic process for identifying shared meanings within participants' narratives and describing the essential structure of a lived experience. The analysis drew primarily on participants' reflective written responses, supported by semi-structured Zoom interview transcripts and follow-up clarifications. Consistent with the qualitative phenomenological design, no statistical procedures were employed because the analysis focused on interpreting the meanings participants attributed to their experiences.

Qualitative data were organized and coded using NVivo, which served as the primary tool for data Management throughout the analysis. As Creswell and Poth (2024) explained, phenomenological inquiry seeks to understand the meanings individuals attribute to their lived experiences. The analysis began with repeated readings of the written narratives and interview transcripts to develop a comprehensive understanding of participants' accounts. Significant statements related to the phenomenon were then identified and extracted, after which formulated meanings were developed while remaining faithful to participants' intended perspectives.

The formulated meanings were organized into thematic clusters, thereby identifying emergent themes. NVivo supported this process by facilitating code organization, retrieval of significant statements, and comparison of participant responses. Consistent with Neubauer et al. (2023), phenomenological analysis extends beyond merely describing experiences to reveal the meanings and essences embedded in participants' narratives. These themes were synthesized into an exhaustive description and subsequently refined into a fundamental structure that captured the essence of implementing virtual laboratories in fully online science instruction.

To strengthen the credibility of the findings, member checking was conducted by returning the interpreted responses and thematic descriptions to the participants for verification. This process allowed participants to confirm that the interpretations accurately reflected their experiences and intended meanings.

The resulting emergent themes, exhaustive description, and fundamental structure served as the foundation for the Proposed Instructional Guide for Implementing Virtual Laboratories in Fully Online Science Instruction. Grounding the guide in participants' lived experiences ensured that its instructional objectives and recommended strategies reflected the realities of implementing virtual laboratories in fully online science education.

Trustworthiness of the Study

To ensure the rigor and trustworthiness of this phenomenological inquiry, the study adhered to the criteria of credibility, transferability, dependability, and confirmability proposed by Lincoln and Guba (1985).

Credibility. Credibility was established through prolonged engagement with the data, follow-up clarifications, and member checking. Reflective written responses served as the primary data source, while semi-structured Zoom interviews provided opportunities to clarify and expand on participants' written accounts. The researcher repeatedly reviewed the written

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responses and interview transcripts to develop a comprehensive understanding of participants' experiences. Direct quotations were incorporated throughout the presentation of findings to preserve participants' voices and ensure that the interpretations accurately reflected their intended meanings. Member checking further strengthened credibility by allowing participants to review and verify the interpreted responses and thematic descriptions.

Transferability. Transferability was enhanced through thick description. Detailed information about the research setting, participant characteristics, inclusion criteria, and instructional contexts was provided to help readers assess the applicability of the findings to similar educational settings and populations.

Dependability. Dependability was strengthened through the maintenance of a systematic audit trail documenting participant recruitment, data collection, data Management, coding, and analysis. The researcher consistently followed Colaizzi's phenomenological method, supported by NVivo for organizing and managing qualitative data. The use of validated research instruments, standardized data collection procedures, and systematic documentation of analytical decisions further enhanced the transparency and consistency of the research process.

Confirmability. Confirmability was established through reflexivity and bracketing. Because the researcher had prior professional experience in online science instruction and was professionally acquainted with the participants through previous employment, reflexive notes were maintained throughout the study to acknowledge and monitor potential assumptions and biases. During analysis, the researcher continually returned to participants' narratives to ensure that the formulated meanings, emergent themes, and interpretations remained grounded in their accounts and direct quotations rather than personal perspectives. These practices strengthened the objectivity and trustworthiness of the findings.

Ethical Considerations

This study adhered to established ethical principles for qualitative research involving human participants. Ethical standards were observed throughout the investigation to protect the rights, dignity, and wellbeing of the participants while exploring their lived experiences of implementing virtual laboratories in fully online science instruction.

Prior to data collection, approval was obtained from the research adviser and the appropriate ethics review committee. Invitation letters and informed consent forms were distributed, and participation was entirely voluntary. Participants were informed of the purpose of the research, the procedures involved, and their right to decline or withdraw at any time without penalty.

Confidentiality and anonymity were strictly maintained throughout the study. Pseudonyms or participant codes replaced personal identifiers, and all written responses, follow-up clarifications, interview records, and research documents were stored in password-protected files accessible only to the researcher. As emphasized by Creswell and Poth (2024), protecting participants' privacy and ensuring voluntary participation are fundamental ethical responsibilities in qualitative inquiry.

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To further uphold ethical research practice, participants were given the opportunity to review and verify the summarized interpretations of their responses through member checking. Throughout the investigation, the researcher maintained the principles of respect, integrity, confidentiality, and academic honesty to ensure the ethical and responsible representation of participants' experiences.

Chapter 4

PRESENTATION, ANALYSIS, AND INTERPRETATION OF DATA

This chapter presents, analyzes, and interprets qualitative findings from the narratives of seven certified online science teachers employed in fully online public-school programs across selected U.S. states. It addresses the central research problem by examining how participants experienced, interpreted, and attributed meaning to the implementation of virtual laboratories in online science instruction. The discussion highlights their lived experiences, the challenges and contextual realities they encountered, the instructional adaptations they employed, and the insights that emerged from their teaching practices.

Consistent with Colaizzi's (1978) phenomenological method and supported by NVivo for qualitative data Management, participants' narratives were analyzed by identifying significant statements, formulating meanings, clustering related meanings into themes, and developing emergent themes that captured the essence of the shared experience. Throughout the presentation of findings, direct quotations are included to preserve participants' voices and demonstrate how the interpretations were grounded in the data.

For clarity and organization, the findings are presented in accordance with the study's four corollary questions. Table 1, "Certified Online Science Teachers' Experiences and Meanings," presents participants' lived experiences and the meanings they attributed to the implementation of virtual laboratories. Table 2, Challenges Encountered by Certified Online Science Teachers in Implementing Virtual Laboratories, focuses on the challenges and contextual realities that influenced implementation. Table 3, Instructional Decisions and Teaching Adaptations of Certified Online Science Teachers During Virtual Laboratory Implementation, presents the instructional decisions and adaptive practices that emerged from participants' experiences. Each table illustrates the progression from significant statements to formulated meanings, theme clusters, and emergent themes, demonstrating how the findings were developed through Colaizzi's phenomenological analysis.

The chapter concludes with the presentation of the Proposed Instructional Guide for Virtual Laboratory Implementation in Fully Online Science Instruction, a research-informed resource grounded in the study's findings and designed to Support online science teachers in their instructional practice.

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Table 1

Certified Online Science Teachers' Experiences and Meanings

Significant Statements	Formulated Meaning	Theme Cluster	Emergent Theme
"Before the lesson, I identify the target standard and learning objective, select or modify a virtual lab... and prepare guiding questions, clear instructions, and a rubric." (CP4)	Aligning virtual laboratories with instructional objectives and supports.	TC1: Purposeful Instructional Planning for Meaningful Virtual Laboratory Experiences	Theme 1. Intentional and Purposeful Planning for Virtual Laboratory Instruction
"Before a virtual lab, I plan around the thinking skill students need rather than just the content, building in checkpoints, anticipated misconceptions, and support." (CP3)	Purposeful planning instruction around student thinking and anticipated learning needs.		
"I plan by reviewing the Amplify lesson objectives and identifying key concepts students need to understand." (CP6)	Reviewing objectives and identifying essential concepts before instruction.		
"I plan the objective, choose a Gizmos or PhET simulation, and prepare guiding questions." (CP7)	Selecting appropriate simulations and preparing inquiry supports.		
"During the lab, I give clear, simple instructions and shift into a facilitator role, monitoring responses, asking probing questions, and using student observations to guide discussion." (CP3)	Responsive and Guided facilitation of inquiry through continuous monitoring and questioning.	TC2: Teacher Facilitation and Responsive Instruction During Virtual Laboratory Learning	Theme 2. Guided Facilitation and Responsive Instruction
"I model how to use the simulation, clarify expectations, monitor students... and ask probing questions to deepen their thinking." (CP4)	Modeling procedures while scaffolding student understanding.		
"I began with direct	Providing real-		

instruction and modeling... while students work, I actively facilitate by monitoring progress, asking guiding questions, and providing real-time support." (CP6)	time responsive instructional guidance throughout the activity.		
"I give a quick demo, set clear expectations, then have students explore... while I check in and ask questions." (CP7)	Guiding exploration through demonstration and continuous support.		
"Students revised answers without embarrassment, debated evidence, and began trusting their observations." (CP3)	Encouraging Inquiry evidence-based reasoning through inquiry.	TC3: Facilitating Inquiry Through Scientific Exploration and Evidence-Based Learning	Theme 3. Inquiry-Based Exploration and Scientific Sense-Making
"Students became highly engaged in testing multiple variables, discussing their results... and independently explaining cause-and-effect relationships." (CP4)	Continuous reflection to support students' conceptual understanding on scientific investigation through manipulation of variables and co		
"Many students made predictions, adjusted variables, and observed outcomes... students became more confident as they repeated trials." (CP6)	Promoting scientific-sense reasoning through repeated experimentation.		
"Students tested variables like temperature and pH... making predictions and connecting the results to real-life examples." (CP7)	Facilitating exploration and application of scientific concepts.		
"We collected data together and discussed findings." (CP1)	Promoting collaborative interpretation of scientific evidence.	TC4: Reflective and Collaborative Meaning-Making for Continuous	Theme 4. Reflection, Collaboration, and Continuous Learning
"I follow up with a discussion	Facilitating		

or reflection where students explain their results and reasoning." (CP6)	reflection to deepen scientific understanding.	Learning	
"We review findings together, connect to real-life concepts, and I follow up with a short reflection or exit ticket." (CP7)	Reinforcing learning through reflection and real-world connections.		
"Afterward, I use a short reflection or exit ticket... and use those insights to shape the next lesson." (CP3)	Using reflective evidence to improve subsequent instruction for continuous learning.		

Table 1 presents the lived experiences and meanings described by certified online science teachers regarding the implementation of virtual laboratories in science instruction. Following Colaizzi's phenomenological process, significant statements from the participants were examined, meanings were formulated from these statements, and related meanings were organized into theme clusters from which the emergent themes were developed. Four interconnected themes emerged from the participants' accounts: Intentional and Purposeful Planning for Virtual Laboratory Instruction; Guided Facilitation and Responsive Instruction; Inquiry-Based Exploration and Scientific Sense-Making; and Reflection, Collaboration, and Continuous Learning. The findings revealed that the implementation of virtual laboratories was experienced not as a single classroom activity, but as a continuous instructional process that began with planning, continued through facilitation and scientific inquiry, and extended into reflection and subsequent instructional decisions. These shared meanings directly address Statement of the Problem 1, which sought to explore how certified online science teachers described their experiences and the meanings they attributed to implementing virtual laboratories in science instruction.

The first theme cluster, Purposeful Instructional Planning for Meaningful Virtual Laboratory Experiences, generated the emergent theme Intentional and Purposeful Planning for Virtual Laboratory Instruction. Across the participants' narratives, meaningful virtual laboratory instruction was consistently portrayed as beginning well before students interacted with a simulation. Teachers emphasized aligning simulations with curriculum standards and learning objectives, anticipating students' misconceptions, selecting appropriate virtual laboratory resources, and preparing instructional supports that would guide scientific inquiry. As one participant explained, "Before the lesson, I identify the target standard and learning objective, select or modify a virtual lab that allows students to manipulate variables, and prepare guiding questions, clear instructions, and a rubric" (CP4). Similarly, another participant shared, "Before a virtual lab, I plan around the thinking skill students need rather than just the content, building in checkpoints, anticipated misconceptions, and support" (CP3). Collectively, these accounts indicate that planning was viewed not merely as lesson preparation but as a deliberate process of

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designing meaningful learning experiences that anticipated students' needs and supported scientific inquiry.

The participants' experiences further suggest that they did not view the virtual laboratory as an instructional tool that could produce meaningful learning simply because it was interactive or technology-based. Instead, the value of the simulation depended on how teachers intentionally connected it to the learning objective, the scientific concepts being developed, and the needs of their students. In this sense, the meaning attached to planning was pedagogical rather than technological. Teachers appeared to evaluate virtual laboratories according to what students needed to understand and do, rather than according to the features of the simulation alone. The formulated meanings in Table 1 reinforce this interpretation, as participants described reviewing essential concepts, anticipating learning needs, selecting appropriate simulations, and preparing inquiry supports before implementation.

This experience reflects the relationship among technological, pedagogical, and content considerations described in the TPACK framework. The participants were not simply choosing a digital resource; they were making decisions about how technology could support particular science content through appropriate instructional strategies. Their accounts also reflect a constructivist orientation because planning focused on creating conditions in which students could investigate concepts, manipulate variables, confront misconceptions, and develop understanding through guided experiences. Purposeful planning therefore emerged as a foundation upon which the remaining experiences of facilitation, inquiry, and reflection were built. This interpretation is consistent with previous qualitative studies showing that purposeful instructional planning enables teachers to design inquiry-oriented online science learning experiences while addressing learners' diverse needs and misconceptions.

The second theme cluster, Teacher Facilitation and Responsive Instruction During Virtual Laboratory Learning, yielded the emergent theme Guided Facilitation and Responsive Instruction. Rather than viewing themselves as passive observers, participants consistently described their role as active facilitators who modeled procedures, clarified expectations, monitored learners' progress, and provided continuous instructional guidance throughout the activity. One participant stated, "During the lab, I give clear, simple instructions and shift into a facilitator role, monitoring responses, asking probing questions, and using student observations to guide discussion" (CP3). Another explained, "I model how to use the simulation, clarify expectations, monitor students... and ask probing questions to deepen their thinking" (CP4). These findings suggest that effective virtual laboratory implementation depended on teachers' continuous instructional responsiveness as students constructed scientific understanding.

The shared experiences of the participants indicate that teacher presence remained important even when students were independently manipulating a virtual simulation. Giving students access to a virtual laboratory did not remove the need for instruction; instead, it changed the nature of the teacher's role. Participants described moving between modeling, monitoring, questioning, clarifying, and providing support depending on what students demonstrated during the activity. Their experiences therefore gave meaning to facilitation as an active and responsive process rather than simply allowing students to independently complete a digital task.

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This finding is particularly relevant in fully online instruction, where teachers and students do not share a physical laboratory space. In such an environment, teachers cannot depend on physical proximity to observe every action or immediately intervene when confusion occurs. The participants' emphasis on check-ins, probing questions, demonstrations, and real-time support suggests that they intentionally created forms of instructional presence within the online environment. Viewed through the Community of Inquiry framework, these practices demonstrate the importance of teaching presence in organizing learning experiences, directing attention, and facilitating students' engagement with scientific ideas. At the same time, questioning and guided discussion supported cognitive presence by requiring students to explain observations and think about the scientific meaning of what occurred during the simulation.

Thus, the meaning derived from this experience was not simply that teachers needed to "help" students use virtual laboratories. Rather, participants experienced facilitation as a necessary bridge between students' interaction with technology and their understanding of the science represented by that technology. Similar observations have been reported in earlier studies emphasizing that active teacher facilitation is essential for sustaining engagement, inquiry, and conceptual learning in online science environments.

The third theme cluster, Facilitating Inquiry Through Scientific Exploration and Evidence-Based Learning, generated the emergent theme Inquiry-Based Exploration and Scientific Sense-Making. Participants described virtual laboratories as learning environments where students actively investigated scientific concepts by making predictions, manipulating variables, observing outcomes, discussing evidence, and explaining scientific relationships. As one participant shared, "Students became highly engaged in testing multiple variables, discussing their results... and independently explaining cause-and-effect relationships" (CP4). Likewise, another participant observed that "Many students made predictions, adjusted variables, and observed outcomes" (CP6). Analysis of these narratives revealed that virtual laboratories were experienced as environments that promoted inquiry and evidence-based reasoning rather than passive content delivery.

The participants' descriptions reveal that the meaningful part of the virtual laboratory experience was not simply students' ability to manipulate objects or variables on a screen. What appeared more significant to teachers was what students did intellectually with the results of those manipulations. Students predicted, observed patterns, reconsidered responses, discussed evidence, and explained relationships. One participant's observation that students revised answers without embarrassment and began trusting their observations further suggests that the virtual environment provided opportunities for students to reconsider their initial thinking on the basis of evidence. In this way, experimentation became part of the process through which students developed scientific understanding rather than merely a procedure for obtaining a correct answer.

This finding provides a deeper understanding of what participants meant when they described virtual laboratories as meaningful instructional experiences. For these teachers, meaningful implementation involved creating opportunities for students to behave as active investigators. Repeated trials and manipulation of variables allowed students to observe

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consequences, compare outcomes, and use those observations to support explanations. The experiences described by participants therefore reflect the constructivist view that learners develop understanding through active engagement with experiences and through the interpretation of evidence rather than through the passive reception of information.

The findings also show that scientific sense-making was closely connected to the facilitation described in the preceding theme. Inquiry did not occur separately from teacher guidance. Participants first established expectations and supported students through modeling and questioning, and students then used the virtual environment to investigate and interpret scientific relationships. This relationship suggests that guided facilitation and learner inquiry were complementary aspects of the same experience. Teachers provided sufficient structure to support investigation while still allowing students opportunities to make predictions, test variables, observe outcomes, and develop explanations. This interpretation aligns with previous research identifying inquiry as a defining characteristic of meaningful virtual laboratory instruction.

The fourth theme cluster, Reflective and Collaborative Meaning-Making for Continuous Learning, gave rise to the emergent theme Reflection, Collaboration, and Continuous Learning. Participants explained that meaningful virtual laboratory experiences extended beyond the completion of simulations through collaborative discussions, reflective dialogue, and ongoing instructional reflection. One participant stated, “We review findings together, connect to real-life concepts, and I follow up with a short reflection or exit ticket” (CP7), while another shared, “Afterward, I use a short reflection or exit ticket... and use those insights to shape the next lesson” (CP3). These accounts suggest that reflection and collaboration enabled teachers to interpret students’ understanding, connect scientific concepts to authentic contexts, and make informed instructional decisions for subsequent lessons.

A deeper examination of these accounts indicates that reflection served two related purposes. For students, reflection created an opportunity to explain results, discuss evidence, make connections, and consolidate what had been learned during the investigation. For teachers, the same reflective process provided information about how students understood the experience. Reflections, discussions, and exit tickets therefore became more than activities used to close a lesson; they functioned as evidence that teachers could use to determine what students understood and what required further attention.

The participants’ experiences also suggest that the completion of a simulation did not represent the end of learning. Scientific meaning continued to develop when students and teachers discussed findings and connected observations to scientific concepts and real-life situations. This is consistent with the Community of Inquiry framework, particularly cognitive and social presence, because understanding was strengthened through reflection, explanation, and collaborative interpretation. The experience also reflects constructivist principles in which learners refine their understanding by connecting new experiences with existing knowledge and by explaining their reasoning to others.

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Importantly, reflection also reveals something about the teachers' own meaning-making. CP3's use of students' reflective evidence to "shape the next lesson" shows that teachers were themselves learning from the implementation process. They interpreted students' responses and used those interpretations to make subsequent instructional decisions. Thus, reflection operated in two directions: students reflected to make sense of their scientific experiences, while teachers reflected on evidence of student learning to improve instruction. This finding is consistent with previous qualitative research that recognizes collaborative reflection as an essential component of inquiry-based science instruction because it supports deeper conceptual understanding and continuous instructional improvement.

Taken together, the findings indicate that certified online science teachers experienced the implementation of virtual laboratories as an intentional, guided, inquiry-oriented, and reflective instructional process. More importantly, the four themes reveal a connected structure within that experience. Purposeful planning established the conditions for learning; guided facilitation supported students as they entered and navigated the investigation; inquiry provided opportunities for students to explore scientific relationships and reason from evidence; and reflection allowed both students and teachers to interpret what occurred and use those understandings to support continued learning. Reflection could then inform subsequent planning, making the experience cyclical rather than linear.

This interconnected process provides a deeper response to Statement of the Problem 1. The participants did not derive meaning from virtual laboratories primarily as technological alternatives to physical laboratory activities. Instead, their narratives indicate that the significance of virtual laboratories was grounded in what teachers and students were able to accomplish through them when technology was combined with purposeful pedagogy. Across their accounts, the teacher remained central as a planner, facilitator, observer, questioner, and reflective practitioner, while students were positioned as active participants who predicted, explored, interpreted evidence, discussed findings, and constructed scientific explanations.

As reflected in the participants' lived experiences, the shared experience therefore suggests that meaningful virtual laboratory implementation was understood less as the use of a digital simulation and more as the intentional creation of an online environment for scientific inquiry and sense-making. Technology provided the environment for investigation, but purposeful planning, teacher presence, student inquiry, collaboration, and reflection gave that environment instructional meaning. This shared meaning brings together the four emergent themes and captures the essence of how the participants described experiencing virtual laboratory implementation in fully online science instruction.

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Table 2

Challenges Encountered by Certified Online Science Teachers in Implementing Virtual Laboratories

Significant Statements	Formulated Meaning	Theme Cluster	Emergent Theme
"Sometimes due to technical issues, things take longer than I expect." (CP1)	Technical issues extending instructional time	TC1: Technology Access and Instructional Continuity Challenges	Theme 1. Technological Access and Connectivity Barriers
"The biggest recurring challenge is still internet instability." (CP2)	Experiencing unstable internet during virtual laboratory sessions		
"Several students were disconnected due to unstable internet." (CP4)	Student disconnection of access affecting participation		
"What was missing at times was consistent tech support and clear troubleshooting guides, especially when students had login or device issues." (CP7)	Limited troubleshooting support for access issues		
"Students who were able to access the lab immediately started rushing through it, answering based on quick assumptions rather than evidence." (CP3)	Students rushing through simulations without evidence-based thinking	TC2: Challenges in Sustaining Student Engagement and Conceptual Understanding	Theme 2. Student Engagement and Conceptual Misunderstandings
"One challenge is when some students get distracted or move too quickly through the online activity without carefully reading the questions." (CP5)	Difficulty maintaining student engagement and focus during online activities		
"Some students were either clicking randomly without understanding the purpose, while others were hesitant to participate due to confusion." (CP6)	Random clicking and hesitation due to confusion		
"Some were clicking through	Completing		

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without really understanding the concepts." (CP7)	simulations without conceptual understanding		
"I shifted everyone into a brief low-tech activity using screenshots from the simulation, asking students to observe, predict outcomes, and explain their thinking while technical issues were resolved." (CP3)	Using alternative low-tech supports during access problems	TC3: Adaptive Instructional Responses to Learning Challenges	Theme 3. Instructional Adjustment and Responsive Facilitation
"I paused the activity, provided a recorded walkthrough and screenshots of the lab, simplified the task into smaller steps, and responsed and followed up with one-on-one check-ins and alternative data sets." (CP4)	Simplifying tasks to provide alternative supports and responsive Facilitation		
"I paused the activity and re-modeled the process step-by-step, thinking aloud as I adjusted variables and explained the cause-and-effect relationships." (CP6)	Re-modeling and adjust instructional task and procedures to address confusion		
"I paused the class, modeled how to think through one example, and gave clearer guiding questions." (CP7)	Clarifying expectations through modeling and guiding questions		
"Sometimes not enough time or certain websites may be blocked by the school." (CP1)	Limited instructional time and blocked digital resources	TC4: Institutional and Organizational Constraints Affecting Implementation	Theme 4. Institutional Support and Workload Constraints
"What is still missing? Grading workload for virtual apps." (CP2)	Grading workload associated with virtual applications		
"What is often missing is protected time for teachers to practice with new tools and plan backups before using	Need for protected planning and preparation time		

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virtual labs live." (CP3)			
"Limited advanced training on maximizing simulation features, insufficient dedicated time for collaborative planning, and occasional delays in technical response have sometimes made implementing virtual labs more challenging." (CP4)	Insufficient training, planning time, and delayed technical support		

Table 2 presents the challenges encountered by certified online science teachers during the implementation of virtual laboratories in fully online science instruction. Following Colaizzi's phenomenological process, significant statements were extracted from the participants' narratives, meanings were formulated from their accounts, and related meanings were organized into theme clusters that subsequently generated four emergent themes: Technological Access and Connectivity Barriers; Student Engagement and Conceptual Misunderstandings; Instructional Adjustment and Responsive Facilitation; and Institutional Support and Workload Constraints. The findings revealed that the challenges associated with virtual laboratory implementation extended beyond technological concerns and involved interconnected issues related to access, student learning, instructional practice, and institutional conditions. These findings directly address Statement of the Problem 2, which sought to identify the challenges encountered by certified online science teachers in implementing virtual laboratories in fully online science instruction.

The first theme cluster, Technology Access and Instructional Continuity Challenges, generated the emergent theme Technological Access and Connectivity Barriers. Across the participants' narratives, unstable internet connections, interrupted access to virtual laboratory platforms, extended instructional time due to technical disruptions, and limited technical support emerged as recurring obstacles during implementation. One participant shared, "The biggest recurring challenge is still internet instability" (CP2), while another explained, "Sometimes due to technical issues, things take longer than I expect" (CP1). CP4 similarly described students becoming disconnected because of unstable internet, while CP7 identified inconsistent technical support and the absence of clear troubleshooting guidance when students encountered login or device-related concerns. Collectively, these accounts indicate that technological barriers disrupted instructional continuity and limited students' opportunities to participate fully in virtual laboratory activities.

The participants' accounts show that technological difficulty was experienced as more than an inconvenience associated with online learning. When students lost connection, could not log in, or experienced device-related problems, the planned sequence of instruction was also interrupted. Time intended for scientific investigation could instead be spent restoring access, repeating directions, troubleshooting technical problems, or helping students rejoin an activity already in progress. Thus, connectivity affected not only whether students could enter the virtual laboratory but also whether teachers could maintain the continuity and pacing of the scientific investigation.

The experience also reveals an issue of participation and access to the learning experience. In a physical classroom, students generally have access to the same laboratory environment once materials are provided. In fully online instruction, however, participation in a virtual laboratory is partly dependent on conditions that may be outside the immediate control of the teacher, such as internet stability, device functionality, platform access, and available technical assistance. CP4's observation that several students were disconnected demonstrates how technological instability can create differences in students' opportunities to participate in the same instructional activity. Consequently, technological access became closely connected with instructional access.

From a TPACK perspective, these experiences further demonstrate that successful technology integration depends not simply on teachers knowing how to use a digital resource. Even when teachers intentionally selected a virtual laboratory for an appropriate science concept, technological conditions could interfere with the planned relationship among technology, pedagogy, and content. The participants therefore experienced technology simultaneously as an instructional opportunity and a potential source of disruption. This interpretation is consistent with qualitative studies identifying internet connectivity, access to digital resources, and inadequate technical support as persistent challenges affecting online science instruction.

The second theme cluster, Challenges in Sustaining Student Engagement and Conceptual Understanding, resulted in the emergent theme Student Engagement and Conceptual Misunderstandings. Although students were generally able to access the simulations, participants consistently described maintaining meaningful engagement and promoting conceptual understanding as ongoing instructional challenges. Students frequently rushed through activities, relied on assumptions rather than scientific evidence, became distracted, clicked randomly, hesitated because of confusion, or completed simulations without fully understanding the scientific concepts being explored. As CP3 explained, "Students who were able to access the lab immediately started rushing through it, answering based on quick assumptions rather than evidence." Similarly, CP6 observed that some students clicked randomly or hesitated because they were uncertain about how to proceed, while CP7 noted that some learners completed simulations without fully understanding the concepts being explored.

These experiences reveal an important distinction between technological access, behavioral engagement, and conceptual engagement. A student may successfully access the virtual laboratory and manipulate the simulation without necessarily engaging in scientific reasoning. Likewise, completing the assigned simulation does not automatically demonstrate that the learner understands the scientific concept represented by it. The participants' observations of rushing, random clicking, distraction, and completion without understanding indicate that visible activity within a simulation can sometimes give the appearance of participation without providing evidence of meaningful scientific learning.

This distinction is particularly significant for fully online science instruction because teachers have fewer opportunities to observe students' behaviors directly than they would in a physical laboratory. A completed digital task may therefore provide limited information about how thoughtfully a student interacted with the investigation. The challenge for teachers was not simply keeping students "on task," but determining whether students were making predictions, attending to evidence, recognizing relationships among variables, and developing explanations from their observations.

Viewed through a constructivist perspective, the participants' experiences suggest that interaction with a simulation alone is insufficient for constructing scientific understanding. Meaningful learning requires students to interpret their experiences, connect observations to prior knowledge, examine evidence, and revise their thinking when necessary. The difficulties described by participants show that the interactive characteristics of virtual laboratories do not automatically produce inquiry. Without purposeful guidance, students may interact with the technological features of a simulation while remaining conceptually disconnected from the scientific phenomenon being represented.

The finding also relates to cognitive presence within the Community of Inquiry framework. Students must move beyond simply interacting with the digital environment toward exploring ideas, interpreting evidence, and developing explanations. The participants' difficulty in sustaining this type of engagement suggests that maintaining cognitive presence in virtual laboratory instruction requires continued teacher monitoring, questioning, and instructional support. Thus, successful virtual laboratory implementation required more than technological access; it depended equally on sustained engagement, careful guidance, and evidence-based scientific thinking. Similar findings have been reported in qualitative studies identifying student engagement and conceptual understanding as ongoing challenges in fully online science learning environments.

The third theme cluster, Adaptive Instructional Responses to Learning Challenges, gave rise to the emergent theme Instructional Adjustment and Responsive Facilitation. Although this theme highlights teachers' responses, the narratives also reveal the instructional demands that required immediate adaptation during virtual laboratory implementation. Participants described pausing activities, simplifying learning tasks, providing alternative instructional resources, re-modeling scientific procedures, offering clearer guiding questions, and providing individualized support when students encountered technological or conceptual difficulties. CP3 explained, "I shifted everyone into a brief low-tech activity using screenshots from the simulation, asking students to observe, predict outcomes, and explain their thinking while technical issues were resolved." Similarly, CP4 described providing a recorded walkthrough, screenshots, smaller instructional steps, one-on-one check-ins, and alternative data sets when students experienced difficulty.

These accounts show that an important challenge of virtual laboratory implementation was the unpredictability of instruction. Teachers could prepare a lesson and select an appropriate simulation, yet the actual implementation could change depending on students' access, understanding, and responses. The need to pause instruction, shift to screenshots, simplify tasks,

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or re-model procedures indicates that teachers could not always follow the lesson exactly as originally planned. Instead, they had to interpret what was happening during the lesson and decide how to maintain learning despite emerging barriers.

Importantly, the alternative strategies described by participants were not simply attempts to keep students occupied while technical problems were resolved. CP3, for example, retained the scientific thinking required by the activity by asking students to observe, predict, and explain using screenshots from the simulation. This suggests that teachers attempted to preserve the learning purpose of the investigation even when the original technological pathway became unavailable. Similarly, re-modeling procedures and breaking tasks into smaller steps allowed teachers to respond to conceptual confusion without abandoning the intended science learning.

This finding adds another dimension to the challenges identified in SOP 2. The difficulty was not only the occurrence of technological or conceptual problems; it was also the additional instructional responsibility placed on teachers to recognize those problems and respond to them in real time. Teachers therefore experienced virtual laboratory implementation as requiring flexibility, judgment, and preparedness for alternative approaches.

This theme should also be distinguished from the instructional decision-making examined under SOP 3. Within Table 2, responsive facilitation represents the instructional demand created by challenges: teachers were required to adjust because barriers emerged during implementation. Table 3 can subsequently examine more deeply how teachers made those decisions and adapted their practices. In the context of SOP 2, the present finding demonstrates that continuous adaptation itself became one of the challenges of implementing virtual laboratories in a fully online environment.

The participants' responses also reflect teaching presence within the Community of Inquiry framework because teachers actively redirected, modeled, clarified, and supported learning when difficulties occurred. Their actions likewise illustrate the pedagogical dimension of TPACK, as teachers modified the way technology was used while maintaining attention to the intended science content. This interpretation aligns with previous research emphasizing instructional responsiveness as an essential characteristic of effective online science teaching when unexpected barriers to learning arise.

The fourth theme cluster, Institutional and Organizational Constraints Affecting Implementation, generated the emergent theme Institutional Support and Workload Constraints. Participants described organizational conditions that influenced their ability to implement virtual laboratories effectively, including limited instructional time, restricted access to digital resources, grading demands associated with virtual laboratory activities, insufficient planning time, delayed technical assistance, and limited professional learning opportunities. As CP4 reflected, "Limited advanced training on maximizing simulation features, insufficient dedicated time for collaborative planning, and occasional delays in technical response have sometimes made implementing virtual labs more challenging." Likewise, CP2 highlighted the grading workload associated with virtual applications, while CP3 emphasized the need for protected time to practice with new tools and prepare backup plans before using virtual laboratories live.

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These accounts broaden the understanding of virtual laboratory challenges beyond what occurs between teachers and students during the lesson. Participants' experiences suggest that the quality of implementation was also shaped by the organizational environment surrounding instruction. Teachers needed time to learn unfamiliar platforms, examine simulations, anticipate possible problems, prepare alternative activities, assess student work, and collaborate with others. When these conditions were limited, the responsibility for successful implementation remained with the teacher even though some of the barriers originated outside the teacher's direct control.

The need for protected planning time is particularly meaningful when considered alongside the findings of Table 1. Participants previously described purposeful planning as an essential part of meaningful virtual laboratory instruction. However, the accounts in Table 2 show that teachers may value extensive preparation while simultaneously experiencing institutional conditions that limit their ability to carry it out. This creates a tension between what teachers understand effective virtual laboratory instruction requires and the time or resources available to accomplish it.

The same tension is visible in participants' comments about technical support and professional learning. Teachers were expected to integrate digital laboratory tools into science instruction, yet some described inadequate troubleshooting assistance or insufficient advanced training. Their accounts suggest that successful implementation cannot be understood entirely as an individual teacher competency. Even a knowledgeable and responsive teacher may encounter limitations when websites are blocked, technical responses are delayed, preparation time is insufficient, or opportunities to develop expertise with simulation features are limited.

This finding points to the shared responsibility involved in implementing virtual laboratories. Teachers play a central instructional role, but institutions also shape the conditions under which teachers can use technology effectively. From a TPACK perspective, teachers may develop the knowledge necessary to integrate technology, pedagogy, and science content, but organizational structures influence whether that knowledge can be enacted consistently in practice. Administrative support, access to appropriate digital resources, technical assistance, collaborative planning opportunities, and professional learning therefore form part of the broader context in which virtual laboratory instruction occurs. This finding is consistent with previous qualitative research highlighting administrative support, professional learning opportunities, and organizational resources as important factors influencing successful online science instruction.

Overall, the narratives demonstrate the findings indicate that certified online science teachers experienced the challenges of implementing virtual laboratories as interconnected dimensions of fully online science instruction rather than as isolated difficulties. Technological instability could interrupt access and instructional continuity; interrupted or superficial participation could affect students' engagement and conceptual understanding; these difficulties could require immediate instructional adaptation; and teachers' ability to prepare for and respond to such challenges could itself be influenced by institutional resources, time, training, and technical support. The four themes therefore reveal a relationship among technological, learner-centered, instructional, and organizational conditions.

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This relationship provides a deeper response to Statement of the Problem 2. The challenges encountered by participants were not limited to whether a simulation functioned properly. Rather, teachers experienced virtual laboratory implementation as requiring them to manage multiple layers of uncertainty at the same time. They had to maintain technological access, determine whether students were meaningfully engaged, identify conceptual misunderstandings, modify instruction when difficulties emerged, and work within the constraints of available institutional support and resources.

The participants' narratives further suggest that these challenges could influence one another. A connectivity problem could reduce a student's participation; interrupted participation could contribute to confusion or incomplete understanding; these difficulties could require the teacher to pause or modify instruction; and responding effectively could require additional time, preparation, or technical assistance. In this way, a challenge originating in one area could create additional demands in another. The experience of implementing virtual laboratories was therefore shaped by the interaction among technology, learners, pedagogy, and the institutional environment.

The shared meaning emerging from these experiences indicates that the central challenge of virtual laboratory implementation was not technology alone, but sustaining meaningful science learning when technological, instructional, learner-related, and organizational conditions were continually interacting. Participants responded by troubleshooting, modifying activities, providing alternative resources, re-modeling procedures, and supporting students individually. Their accounts demonstrate that successful virtual laboratory implementation in fully online science instruction depends not only on access to digital simulations but also on teachers' capacity to respond to emerging difficulties and on institutional conditions that make such responsiveness possible.

Table 3

Instructional Decisions and Teaching Adaptations of Certified Online Science Teachers During Virtual Laboratory Implementation

Significant Statements	Formulated Meaning	Theme Cluster	Emergent Theme
"Depends on the class. Younger students need more modeling, so they stay on task and understand how the VLs work." (CP1)	Adapting instruction according to learners' characteristics	TC1: Learner-Centered Instructional Planning and Decision-Making	Theme 1. Learner-Centered Instructional Decision-Making
"My decisions about using a virtual lab are guided first by the standards and the type of thinking students need to practice." (CP3)	Aligning instructional decisions with standards and cognitive		

	demands		
"My decisions about when and how to use a virtual lab are influenced by the alignment to standards and learning objectives, pacing within the curriculum, students' prior knowledge and readiness." (CP4)	Considering standards, pacing, and learner readiness when making instructional decisions		
"My decisions are guided primarily by learning objectives and NGSS standards... I also consider student readiness, pacing, device access, and assessment goals." (CP6)	Integrating instructional, technological, and assessment considerations into decision-making		
"Over time, my approach to virtual labs has shifted from focusing on completion to prioritizing student thinking and evidence-based reasoning." (CP3)	Shifting instructional emphasis toward student thinking and reasoning	TC2: Reflective Adaptation of Instructional Practices	Theme 2. Adaptive Instruction Through Reflection and Responsiveness
"My teaching strategies... shifted from heavily guided, step-by-step instruction to a more inquiry-based and student-centered approach." (CP4)	Adjusting and adapt instructional approaches in response to students' learning experiences		
"My approach to virtual labs has shifted from teacher-directed instruction to a more student-centered, inquiry-based model." (CP6)	Adapting facilitation to encourage greater student independence		
"I've shifted from just having students complete virtual labs to making them more structured and interactive." (CP7)	Revising instructional practices to increase and reflect structure and interaction		
"Modeling and sharing my screen at the beginning, then regular check-ins later."	Guiding learners through modeling and	TC3: Responsive Facilitation to	Theme 3. Active Facilitation and Student Support

(CP1)	continuous monitoring	Support Student Learning	
"I position myself as a facilitator who asks questions and validates thinking, helping students feel supported without taking over their learning." (CP3)	Actively facilitate learning through questioning and instructional support		
"I make sure students feel guided, involved, and connected by providing clear step-by-step instructions... asking frequent check-in and probing questions." (CP4)	Sustaining student participation through continuous instructional student support		
"I ensure students feel guided... by providing clear, step-by-step instructions... checking for understanding and encouraging participation." (CP6)	Monitoring understanding while encouraging participation		
"The photosynthesis VL is fairly prescriptive, so it does not allow students to investigate a question that they devise on their own as much as they might do in a physical lab." (CP1)	Recognizing limitations of virtual laboratory design	TC4: Balancing Technological Affordances with Pedagogical Goals	Theme 4. Balancing Technology, Pedagogy, and Content
"The trade-off was sacrificing some realism and complexity in the technology in exchange for clearer focus on the core content and student thinking." (CP3)	Prioritizing conceptual understanding over technological complexity		
"I accepted the trade-off of using a simplified model with fewer variables so students could more clearly grasp the essential concept." (CP4)	Simplifying technology to maintain conceptual focus		
"A trade-off I made was limiting the number of variables students could explore at once to avoid cognitive overload." (CP6)	Adjusting technological complexity according to students' learning needs		

Table 3 presents the instructional decisions and teaching adaptations of certified online science teachers during the implementation of virtual laboratories in fully online science instruction. Following Colaizzi's phenomenological process, significant statements from the participants were examined, meanings were formulated from their accounts, and related meanings were organized into theme clusters that generated four emergent themes: Learner-Centered Instructional Decision-Making; Adaptive Instruction Through Reflection and Responsiveness; Active Facilitation and Student Support; and Balancing Technology, Pedagogy, and Content. The participants' narratives revealed that instructional decision-making was not experienced as a fixed process established before a lesson began. Instead, teachers continually considered curriculum expectations, learner readiness, students' responses, technological conditions, and evidence of understanding as they determined how virtual laboratories should be used. These findings directly address Statement of the Problem 3, which examined how certified online science teachers made instructional decisions and adapted their teaching practices during virtual laboratory implementation.

The first theme cluster, Learner-Centered Instructional Planning and Decision-Making, generated the emergent theme Learner-Centered Instructional Decision-Making. Across participants' narratives, instructional decisions were consistently guided by curriculum standards, learning objectives, students' readiness, pacing, cognitive demands, and individual learner characteristics prior to the introduction of virtual laboratories. Rather than relying on predetermined instructional routines, participants described intentionally selecting and organizing learning experiences according to the instructional needs of their students. As CP6 explained, "My decisions are guided primarily by learning objectives and NGSS standards... I also consider student readiness, pacing, device access, and assessment goals." Similarly, CP4 shared, "My decisions about when and how to use a virtual lab are influenced by the alignment to standards and learning objectives, pacing within the curriculum, students' prior knowledge and readiness."

These statements reveal that teachers did not base their decisions simply on whether a virtual laboratory was available or technologically appealing. Instead, they considered whether its use was appropriate for a particular group of learners and whether it served the intended science learning objective. CP1's observation that younger students required more modeling further demonstrates that instructional decisions changed according to learner characteristics. The same virtual laboratory could therefore require different levels of structure, modeling, pacing, or support depending on the students who were using it.

The decision-making process described by participants appears to involve the simultaneous consideration of several instructional conditions. Standards and learning objectives established what students were expected to learn, while prior knowledge and readiness helped teachers determine the amount of guidance required. Pacing influenced when a virtual laboratory could be incorporated into the curriculum, while device access and assessment goals shaped how the activity could realistically be implemented. Rather than treating these considerations separately, teachers appeared to weigh them together when deciding when, why, and how to use virtual laboratories.

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This finding reflects the learner-centered character of the participants' decision-making. Their accounts indicate that the technology was adjusted around the instructional situation rather than requiring students to adjust to a predetermined technological activity. Such decisions are consistent with constructivist principles because instruction was organized around learners' existing understanding and their readiness to engage with new scientific experiences. The finding also reflects TPACK, as teachers considered science content, pedagogical approaches, and technological resources simultaneously when determining the appropriateness of a virtual laboratory.

Thus, instructional decision-making was grounded in thoughtful consideration of learners and curriculum expectations rather than the capabilities of the technology itself. Previous qualitative studies similarly demonstrate that effective online science instruction requires teachers to integrate curriculum goals, learner characteristics, and contextual factors when making instructional decisions.

The second theme cluster, Reflective Adaptation of Instructional Practices, resulted in the emergent theme Adaptive Instruction Through Reflection and Responsiveness. Participants described continually refining their instructional approaches based on students' participation, understanding, and learning experiences. Several teachers explained that their practices changed over time as they gained experience implementing virtual laboratories and observed how students responded to different instructional approaches. CP4 reflected, "My teaching strategies... shifted from heavily guided, step-by-step instruction to a more inquiry-based and student-centered approach." Likewise, CP6 shared, "My approach to virtual labs has shifted from teacher-directed instruction to a more student-centered, inquiry-based model." CP3 similarly described moving away from an emphasis on task completion toward greater attention to student thinking and evidence-based reasoning.

These accounts demonstrate that adaptation occurred not only during individual lessons but also across teachers' accumulated experiences with virtual laboratory instruction. Participants reflected on what happened during previous implementations and used those experiences to reconsider how much direction students needed, how activities should be structured, and what kinds of thinking should be emphasized. Instructional adaptation therefore involved professional learning as teachers refined their approaches through experience.

A particularly meaningful shift within the participants' narratives was the movement from teacher control toward greater learner responsibility. Early or heavily guided approaches emphasized modeling and step-by-step instruction, whereas later adaptations placed greater emphasis on inquiry, student thinking, interaction, and independent reasoning. This did not mean that teachers completely withdrew instructional support. Rather, they appeared to reconsider when direct guidance was necessary and when students were prepared to assume greater responsibility for investigating scientific questions.

CP7's statement that virtual laboratories became "more structured and interactive" also illustrates that adaptation did not always mean providing less structure. Instead, teachers adjusted the type and amount of structure according to what they learned from students' experiences. This is important because responsive instruction does not necessarily move in only one direction from teacher-centered to student-centered practice. Depending on students' readiness and the demands of the activity, effective adaptation may involve increasing guidance in one situation and gradually releasing responsibility in another.

At a deeper interpretive level, these accounts reveal reflection as a mechanism for instructional change. Teachers observed students' responses, interpreted what those responses meant for learning, and modified subsequent instruction accordingly. This process reflects the adaptive character of professional practice: experience generated information, reflection gave that experience meaning, and that meaning informed later teaching decisions. Similar qualitative research has shown that reflective practice enables online teachers to make instructional adjustments that better support students' changing learning needs.

The third theme cluster, Responsive Facilitation to Support Student Learning, generated the emergent theme Active Facilitation and Student Support. Participants described translating their instructional decisions into practice through continuous facilitation, modeling, questioning, monitoring, and individualized support during virtual laboratory activities. Rather than directing every aspect of the investigation, they positioned themselves as facilitators who guided students' thinking while encouraging active participation and learner independence. As CP3 explained, "I position myself as a facilitator who asks questions and validates thinking, helping students feel supported without taking over their learning." Likewise, CP4 described providing frequent check-ins, clear step-by-step instructions, and probing questions to sustain student participation throughout the activity.

The participants' descriptions show how instructional decisions became visible in actual teaching practice. Decisions concerning student readiness or the amount of guidance required were enacted through modeling, questioning, check-ins, clarification, and monitoring. CP1, for example, described modeling and screen sharing at the beginning of the activity followed by regular check-ins. CP6 similarly emphasized clear instructions, checks for understanding, and encouragement of participation. These actions indicate that teachers continuously gathered information about how students were progressing and adjusted their support accordingly.

A notable feature of this theme is the balance participants attempted to maintain between support and independence. CP3's description of helping students "without taking over their learning" captures this tension clearly. Too little guidance could leave students uncertain about procedures or scientific concepts, while excessive teacher direction could limit opportunities for inquiry and independent reasoning. The teachers' role therefore involved judging when intervention was necessary and when students should be allowed to continue exploring on their own.

This finding also helps distinguish Table 3 from the challenge-oriented discussion in Table 2. In Table 2, instructional adjustment emerged because technological or conceptual difficulties required teachers to respond. In Table 3, the participants' accounts reveal the decision-making behind responsive teaching itself. Teachers intentionally monitored students, interpreted their needs, and calibrated the amount of instructional assistance provided.

Responsiveness was therefore not only a reaction to problems but an ongoing feature of how they facilitated virtual laboratory learning.

The practices described by participants correspond strongly with teaching presence in the Community of Inquiry framework. Modeling and clear instructions provided instructional direction, while questioning, check-ins, and feedback supported students as they engaged with scientific ideas. At the same time, allowing students to investigate without the teacher taking over supported cognitive presence by maintaining learners' responsibility for interpreting observations and developing understanding. Active facilitation therefore functioned as a means of sustaining both guidance and intellectual independence within the virtual environment.

The fourth theme cluster, Balancing Technological Affordances with Pedagogical Goals, gave rise to the emergent theme Balancing Technology, Pedagogy, and Content. Participants described making deliberate instructional decisions that balanced the capabilities and limitations of virtual laboratory technologies with students' cognitive readiness and conceptual learning needs. Rather than maximizing technological complexity, teachers sometimes simplified simulations, reduced the number of variables students manipulated, or accepted less realistic models when these choices allowed students to focus more clearly on essential science concepts. As CP3 explained, "The trade-off was sacrificing some realism and complexity in the technology in exchange for clearer focus on the core content and student thinking." Similarly, CP4 shared, "I accepted the trade-off of using a simplified model with fewer variables so students could more clearly grasp the essential concept."

These accounts reveal an important principle underlying the participants' instructional decisions: more technologically complex did not necessarily mean more instructionally effective. Teachers evaluated technological features according to whether those features supported or interfered with students' understanding. When additional variables, realism, or technological complexity created unnecessary cognitive demands, participants were willing to simplify the experience to protect the conceptual focus of the lesson.

CP1's observation that a photosynthesis virtual laboratory was "fairly prescriptive" further demonstrates that teachers recognized limitations within virtual laboratory design itself. A simulation may represent a scientific phenomenon effectively while still restricting the kinds of questions students can investigate. Teachers therefore did not treat virtual laboratories as perfect representations of physical laboratory experiences. Instead, they recognized both the affordances and constraints of the available technology and made instructional decisions within those boundaries.

The trade-offs described by CP3, CP4, and CP6 provide a particularly strong connection to TPACK. These participants were negotiating among technological possibilities, pedagogical priorities, and science content rather than allowing one component to determine the lesson. Their willingness to limit technological complexity to reduce cognitive overload or clarify an essential concept demonstrates that technology was subordinate to the learning purpose. The question guiding their decisions was not simply what the simulation could do, but what students needed the simulation to help them understand.

This finding also extends the learner-centered decision-making identified in the first theme. Decisions about standards, readiness, and pacing established whether and how a virtual laboratory should be used, while decisions about technological complexity determined what form that experience should take. In both cases, participants placed student understanding at the center of their choices. Previous research likewise emphasizes that successful virtual laboratory instruction depends on teachers' ability to integrate technological resources with sound pedagogical practices and intended science learning outcomes.

Across the four themes, a clear pattern of instructional decision-making emerges. Teachers first considered the intended learning outcomes and characteristics of their students, then observed how learners responded to instruction, reflected on those experiences, adjusted their teaching practices, and provided varying levels of support as needed. At the same time, they continually evaluated whether the technological features of virtual laboratories supported the science concepts students were expected to understand. Instructional decisions were therefore neither entirely predetermined before the lesson nor limited to immediate reactions during instruction.

The participants' narratives point to a process that can be understood as interpretation followed by instructional action. Teachers considered what students needed, observed what students were doing and understanding, interpreted those observations, and decided whether to model, question, scaffold, simplify, increase independence, or modify the technological experience. Evidence of student learning then contributed to further reflection and subsequent instructional decisions. In this sense, adaptation was recursive: each instructional experience provided information that could shape the next decision.

This pattern provides a direct response to Statement of the Problem 3. Certified online science teachers made instructional decisions by considering the interaction among learning objectives, curriculum standards, learner characteristics, readiness, pacing, technological access, assessment goals, and evidence of student understanding. They adapted their practices through reflection, responsive facilitation, changes in instructional structure, and deliberate decisions about the complexity and use of virtual laboratory technologies. Their decisions therefore emerged from the interaction between what had been planned and what teachers observed during actual instruction.

At the level of shared meaning, the participants' experiences portray instructional adaptation as an integral part of teaching with virtual laboratories rather than an occasional correction when a lesson does not proceed as expected. Teachers learned from implementation, reconsidered their approaches, adjusted the degree of student independence, and negotiated trade-offs between technological sophistication and conceptual clarity. Their accounts portray the online science teacher as an active instructional decision-maker who continually interprets the relationship among learners, science content, pedagogy, and technology.

The underlying meaning across these experiences is that effective virtual laboratory instruction depended less on following a predetermined technological procedure and more on teachers' capacity to make informed judgments as learning unfolded. Virtual laboratories provided opportunities for scientific investigation, but teachers determined how those opportunities were structured, supported, modified, and connected to intended learning outcomes. In this way, instructional decision-making and adaptation became central to transforming a digital simulation into a responsive and meaningful science learning experience.

Proposed Instructional Guide for Implementing Virtual Laboratories in Fully Online Science Instruction

The proposed instructional guide was developed based on the findings of the present study and is grounded in the lived experiences of certified online science teachers as they implement virtual laboratories in fully online science instruction. The objectives of the guide were derived from the identified Statements of the Problem (SOPs) numbers 1, 2, and 3, along with their corresponding meanings and emergent themes, ensuring that each instructional component reflects the participants' shared experiences, instructional practices, challenges encountered, and instructional decisions.

I. Rationale

The Proposed Instructional Guide was developed as a practical, research-informed resource to Support the implementation of virtual laboratories in fully online science instruction for Grades 4–12. It is grounded in the lived experiences of certified online science teachers, whose narratives characterized the implementation of virtual laboratories as an intentional and reflective instructional process shaped by purposeful planning, responsive facilitation, inquiry-based learning, and continuous instructional decision-making. Participants also identified recurring technological, instructional, and contextual challenges—including connectivity issues, student engagement concerns, conceptual misunderstandings, time constraints, and limited institutional Support—that influenced their experiences facilitating virtual laboratories in fully online learning environments.

Drawing on the shared meanings that emerged from the participants’ experiences, the instructional guide translates the study’s findings into practical instructional objectives that address the realities of online science teaching. Specifically, it provides guidance for planning standards-aligned virtual laboratory activities, preparing students for meaningful participation, facilitating inquiry-based learning, differentiating instruction according to learners’ readiness and needs, anticipating and addressing technological and conceptual challenges, using reflection and assessment to guide instructional decisions, and implementing responsive teaching strategies throughout virtual laboratory instruction.

As a research-informed resource, the instructional guide serves as a bridge between the phenomenological findings and classroom practice. Aligning each instructional objective with emergent themes and participants’ lived experiences provides flexible strategies to help online science teachers implement effective virtual laboratory instruction while addressing the diverse demands of fully online science learning environments.

II. Target Users

The Proposed Instructional Guide is primarily intended for certified online science teachers who implement virtual laboratories in fully online public-school settings. It serves as a practical resource for planning, facilitating, assessing, and continuously improving virtual laboratory instruction.

The guide may also benefit instructional coaches and professional development facilitators by supporting pedagogical mentoring and professional learning for online science teachers. In addition, it may serve as a reference for school administrators to strengthen technological infrastructure, promote professional learning opportunities, and enhance instructional systems that Support the effective implementation of virtual laboratories in fully online science learning environments.

III. General Objective

To provide practical guidance for implementing virtual laboratories in fully online science instruction for Grades 4–12 through intentional planning, inquiry-oriented facilitation, responsive instructional decision-making, and reflective practice.

IV. Specific Objectives

At the end of the implementation process, teachers should be able to:

1. Plan standards-aligned virtual laboratory activities that Support intended learning objectives;
2. Prepare students for meaningful participation in virtual laboratory experiences;
3. Facilitate inquiry-based and collaborative virtual laboratory learning;
4. Differentiate instruction according to students' readiness, abilities, and learning needs;
5. Anticipate and address technological and conceptual challenges during implementation;
6. Use reflection and assessment to guide instructional decisions and improve learning; and
7. Apply responsive instructional strategies to address emerging technological and learning needs throughout virtual laboratory instruction.

V. Pre-Laboratory Preparation

Teacher Actions:

1. Identify the targeted learning standards and instructional objectives.

2. Select a virtual laboratory platform (e.g., PhET, Gizmos) that aligns with the lesson objectives.
3. Review the simulation procedures, expected outcomes, and key scientific concepts.
4. Develop guiding questions and inquiry prompts to promote scientific thinking.
5. Anticipate possible student misconceptions and potential technological challenges.
6. Prepare alternative instructional activities or backup resources in case of technical difficulties.
7. Verify that students have access to the required devices, internet connectivity, and virtual laboratory platform.

VI. Teacher Modeling and Orientation

Teacher Actions:

1. Explain the learning objectives and success criteria for the activity.
2. Demonstrate how to access and navigate the virtual laboratory simulation.
3. Model the expected procedures, digital expectations, and scientific practices.
4. Review digital citizenship, online safety, and appropriate use of the simulation.
5. Explain how students will collect data, record observations, and complete the assessment.
6. Clarify expectations for participation, collaboration, and evidence-based explanations.

Suggested Teacher Prompts

- "What do you predict will happen if we change this variable? What evidence supports your prediction?"
- "What observations or data will you collect as you complete the simulation?"
- "How will you know if your prediction is supported by the evidence?"
- "Which variable will you change, and which variables should remain the same?"
- "How will you explain your results using scientific evidence?"

VII. Guided Inquiry Procedures

- Engage: Activate students' prior knowledge by presenting a relevant scientific phenomenon, driving question, or real-world problem that connects to the virtual laboratory investigation.
- Explore: Provide opportunities for students to manipulate variables, make predictions, collect observations, and gather evidence through active investigation.
- Explain: Facilitate evidence-based discussions by asking probing questions, encouraging students to justify their claims, and connecting observations to scientific concepts.

- Elaborate: Extend learning by applying scientific concepts to new situations, comparing findings with peers, and relating results to authentic real-world contexts.
- Evaluate: Assess students' understanding through formative assessments, reflective activities, and evidence-based explanations to inform subsequent instructional decisions.

VIII. Student Collaboration Strategies

Teachers may incorporate the following collaborative learning strategies to promote scientific discourse and peer interaction:

- Breakout room discussions
- Think-Pair-Share activities
- Collaborative digital documents
- Shared data tables
- Online discussion boards
- Collaborative presentations
- Peer feedback and review

Suggested Discussion Questions:

- What patterns or trends did you observe from the simulation?
- How did changing the independent variable affect the outcome?
- What evidence from the simulation supports your explanation?
- How do your findings compare with those of your classmates?
- What scientific concept explains the results you observed?
- If you repeated the investigation, what would you change and why?

IX. Scaffolding and Differentiation

Table 4
Scaffolding and Differentiation Strategies for Virtual Laboratory Implementation

Learner Group	Instructional Strategies
Students Requiring Additional Support	Provide step-by-step instructions; use screenshots and visual guides; chunk directions into smaller tasks; model procedures before independent exploration; provide sentence frames; conduct small-group check-ins.
Advanced Learners	Allow independent investigation; encourage extension questions; provide opportunities for additional experimentation; assign peer-facilitation roles.

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X. Technical Troubleshooting Checklist

Table 5

Technical Troubleshooting Checklist

Phase	**Teacher Actions**
Before the Lesson	Test the simulation; verify internet access; confirm student log-in credentials; prepare backup links and screenshots; download alternative materials.
During the Lesson	Pause and model procedures when difficulties arise; provide recorded demonstrations if needed; offer low-tech alternatives; reassign collaborative partners when necessary.
After the Lesson	Document recurring technical issues and reflect on needed adjustments.

XI. Misconception-Checking Strategies

Teachers should:

1. Ask students to explain their thinking.
2. Use prediction questions.
3. Encourage evidence-based reasoning.
4. Compare predictions with observations.
5. Address misconceptions through guided questioning.
6. Provide corrective examples and additional demonstrations.

Sample Prompts:

- What evidence supports your answer?
- Why do you think that happened?
- Did your observations match your prediction? Why or why not?

XII. Reflection and Assessment

Reflection Questions for Students:

1. What did you discover during the investigation?
2. What evidence supports your conclusion?
3. What challenged your thinking?
4. How did your understanding change?

Assessment Options: Exit tickets; Reflection journals; Discussion responses; Lab reports; Concept maps; and Digital quizzes

XIII. Sample Teacher Checklist

Table 6

Sample Teacher Checklist for Virtual Laboratory Implementation

Phase	Task	Completed
Before the Laboratory	Objectives identified	
	Simulation selected	
	Guiding questions prepared	
	Misconceptions anticipated	
	Technology checked	
	Alternative materials prepared	
During the Laboratory	Procedures modeled	
	Students monitored	
	Questions facilitated	
	Collaboration encouraged	
	Feedback provided	
After the Laboratory	Reflection conducted	
	Student responses reviewed	
	Assessment completed	
	Instructional adjustments noted	

XIV. Sample Student Guide

Table 7

Sample Student Guide for Virtual Laboratory Activities

Phase	Student Responsibilities
Before the Laboratory	Read instructions and review objectives.
During the Laboratory	Make predictions, test variables, record observations, participate in discussions, and ask questions when needed.
After the Laboratory	Explain findings, complete reflections, and submit required outputs.

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XV. Evaluation and Feedback Form

Table 8

Sample Evaluation and Feedback Form for Virtual Laboratory Implementation

Please rate the following:

Indicators	**Excellent**	**Good**	**Fair**	**Needs Improvement**
Instructions were clear				
Simulation was easy to use				
Activities provided opportunities for inquiry				
Collaboration opportunities were adequate				
Reflection activities provided opportunities for reflection				

Open-Ended Feedback:

1. Which aspects of the virtual laboratory experience did you find most helpful?
2. What challenges did you experience?
3. What suggestions do you have for improving future virtual laboratory activities?

Interpretation of the Proposed Output

The proposed instructional guide translates the phenomenological findings of this study into practical objectives and evidence-informed strategies for implementing virtual laboratories in fully online public-school science instruction. Its components were developed from the emergent themes identified in the participants' narratives, ensuring that the recommended practices reflect their experiences in planning instruction, facilitating inquiry, addressing learners' diverse needs, overcoming instructional and technological challenges, and engaging in reflective practice.

Taken together, the guide demonstrates how the meanings participants attributed to their experiences can be transformed into a coherent framework for practice. This study offers certified online science teachers and other educational stakeholders a practical resource for facilitating virtual laboratory instruction while adapting to learners' needs and the unique demands of fully online learning environments.

Essence of the Lived Experience

The lived experience of certified online science teachers implementing virtual laboratories in fully online public-school science instruction is characterized by an intentional, reflective process for facilitating meaningful science learning in digital environments. Rather than viewing virtual laboratories as substitutes for traditional laboratory activities, participants experienced them as opportunities to design authentic learning experiences that required purposeful planning, inquiry-oriented facilitation, responsiveness to learners' needs, and ongoing reflection despite the absence of physical laboratory settings.

Across the participants' narratives, this experience emerged as a dynamic instructional journey. It began with designing learning experiences aligned with curriculum standards, anticipating students' needs, and preparing them for active participation. As instruction unfolded, participants guided inquiry, encouraged scientific exploration, addressed misconceptions, and adapted their teaching in response to learners' engagement, readiness, and developing understanding. Throughout the process, they also navigated technological, instructional, and contextual challenges while maintaining a focus on meaningful science learning in online environments.

Participants likewise described assuming multiple professional roles during virtual laboratory instruction. Beyond serving as planners and facilitators, they became mentors, troubleshooters, observers, and reflective practitioners who continually interpreted students' responses and adjusted instruction to balance curriculum expectations, technological opportunities, and diverse learning needs. Their experiences demonstrated that effective virtual laboratory instruction depended on thoughtful judgment, flexibility, and ongoing responsiveness rather than adherence to predetermined procedures.

The essence of the phenomenon lies in the participants' shared commitment to creating meaningful opportunities for scientific inquiry within fully online learning environments. Their experiences suggest that the effectiveness of virtual laboratories was shaped less by the simulations themselves than by the intentional pedagogical decisions that encouraged active participation, supported scientific reasoning, and promoted reflective learning. Collectively, their narratives portray virtual laboratory instruction as an evolving process of interpreting learners' needs, responding to instructional realities, and facilitating inquiry through deliberate and adaptive teaching practices.

Ultimately, implementing virtual laboratories involves transforming digital learning environments into meaningful spaces for scientific inquiry through intentional planning, responsive facilitation, reflective decision-making, and continuous instructional adaptation. The shared meaning emerging from the participants' lived experiences reveals that virtual laboratory instruction extends beyond the integration of educational technology; it represents a deliberate pedagogical practice focused on fostering meaningful science learning within fully online educational settings.

CHAPTER 5

SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary of the Findings

This study explored the lived experiences of certified online science teachers who implemented virtual laboratories for instruction in fully online public school settings across selected U.S. states. Using Colaizzi's phenomenological method, supported by NVivo for data organization and coding, the participants' narratives were analyzed to identify the shared meanings that characterized their experiences with virtual laboratory instruction.

For Statement of the Problem 1, four emergent themes were identified: (1) Intentional and Purposeful Planning for Virtual Laboratory Instruction, (2) Guided Facilitation and Responsive Instruction, (3) Inquiry-Based Exploration and Scientific Sense-Making, and (4) Reflection, Collaboration, and Continuous Learning. These findings revealed that participants experienced virtual laboratory instruction as an intentional, inquiry-oriented, and reflective process grounded in purposeful planning, guided facilitation, active scientific inquiry, collaborative learning, and continuous reflection. They regarded virtual laboratories as valuable instructional resources that supported conceptual understanding, scientific reasoning, and active student participation while complementing authentic hands-on laboratory experiences.

For Statement of the Problem 2, four themes emerged: (1) Technological Access and Connectivity Barriers, (2) Student Engagement and Conceptual Misunderstandings, (3) Instructional Adjustment and Responsive Facilitation, and (4) Institutional Support and Workload Constraints. Participants described technological, instructional, and contextual challenges as interconnected aspects of online teaching rather than isolated obstacles. Their experiences highlighted issues related to connectivity, student engagement, conceptual misunderstandings, instructional adjustments, workload demands, and limitations in institutional and technical Support. Despite these challenges, they continually adapted their instructional approaches to sustain meaningful virtual laboratory learning.

For Statement of the Problem 3, the analysis yielded four additional themes: (1) Learner-Centered Instructional Decision-Making, (2) Adaptive Instruction Through Reflection and Responsiveness, (3) Active Facilitation and Student Support, and (4) Balancing Technology, Pedagogy, and Content. The findings demonstrated that instructional decision-making was a continuous, learner-centered, and context-responsive process. Participants considered curriculum standards, learning objectives, learner readiness, pacing, assessment requirements, available technologies, and contextual conditions while adapting instruction through facilitation, differentiation, reflection, and purposeful integration of technology, pedagogy, and science content.

For Statement of the Problem 4, the findings informed the development of a Proposed Instructional Guide for Implementing Virtual Laboratories in Fully Online Science Instruction. The guide translated the study's findings into seven research-informed instructional objectives

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focused on standards-aligned planning, meaningful student participation, inquiry-based learning, differentiated instruction, strategies for addressing technological and conceptual challenges, reflective instructional decision-making, and responsive teaching throughout the implementation of virtual laboratories.

Overall, the study demonstrates that implementing virtual laboratories goes beyond integrating digital technologies. Instead, it represents an intentional, inquiry-oriented, learner-centered, and reflective instructional process shaped by purposeful planning, adaptive facilitation, informed decision-making, and continuous reflection. Collectively, these findings provide an empirical foundation for the proposed instructional guide, which may serve as a practical resource for certified online science teachers and educational stakeholders implementing virtual laboratories in fully online science instruction.

Conclusions

Based on the study's findings, the following conclusions were drawn.

First, certified online science teachers perceived the implementation of virtual laboratories as an intentional, inquiry-oriented, and reflective instructional process supported by purposeful planning, guided facilitation, scientific inquiry, collaboration, and continuous reflection. Rather than replacing traditional laboratory activities, virtual laboratories complemented hands-on experiences by providing opportunities for students to investigate scientific concepts, manipulate variables, construct evidence-based explanations, and participate in authentic inquiry within fully online learning environments.

Second, the implementation of the virtual laboratory was shaped by interconnected technological, instructional, and contextual challenges. Teachers encountered issues related to internet connectivity, student engagement, conceptual misunderstandings, instructional adjustments, workload demands, and limitations in institutional Support. These findings suggest that successful implementation depends not only on teachers' instructional responsiveness but also on adequate technological infrastructure, organizational support, and ongoing professional learning opportunities.

Third, instructional decision-making emerged as a continuous, learner-centered, and context-responsive process. Teachers considered curriculum standards, learning objectives, learner readiness, assessment requirements, available technologies, and contextual conditions when adapting instruction. Their experiences demonstrate that effective virtual laboratory instruction requires reflective practice, responsive facilitation, differentiated Support, and the purposeful integration of technology, pedagogy, and science content.

Fourth, the lived experiences of certified online science teachers provided the empirical foundation for developing a Proposed Instructional Guide for Implementing Virtual Laboratories in Fully Online Science Instruction. Grounded in the study's findings, the guide translates participants' experiences into research-informed instructional objectives and practical strategies

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that Support planning, student engagement, inquiry-based learning, differentiated instruction, reflective decision-making, and effective responses to technological and conceptual challenges.

Overall, the study concludes that implementing virtual laboratories goes beyond integrating digital technologies into science instruction. Instead, it represents a deliberate pedagogical process that requires intentional planning, instructional adaptability, reflective decision-making, and sustained responsiveness to learners' needs and the realities of fully online education. These conclusions underscore the importance of institutional Support, continuous professional learning, and research-informed instructional guidance in fostering effective and meaningful virtual laboratory experiences.

Recommendations

Based on the study's findings and conclusions, the following recommendations are offered.

For online science teachers. Certified online science teachers are encouraged to implement virtual laboratories through intentional planning, inquiry-based facilitation, differentiated instruction, and continuous reflection. The proposed instructional guide may serve as a practical resource for designing standards-aligned learning experiences, preparing students for active participation, addressing technological and conceptual challenges, and using assessment evidence to inform instructional decisions.

For school administrators. School administrators are encouraged to strengthen institutional Support for virtual laboratory instruction by ensuring reliable access to digital technologies and simulation platforms, providing relevant professional learning opportunities, and offering timely technical assistance for teachers and students. They may also facilitate the adoption, implementation, and evaluation of the proposed instructional guide within fully online science programs.

For curriculum developers. Curriculum developers may incorporate the proposed instructional guide into science curricula and professional learning initiatives to promote consistent, research-informed virtual laboratory instruction. Curriculum materials should emphasize inquiry-based learning, differentiated instructional strategies, formative assessment, and structured reflection to strengthen science teaching in online environments.

For developers of virtual laboratory platforms and educational technologies. Developers are encouraged to design accessible, user-friendly, and inclusive virtual laboratory platforms that address diverse learner needs. Integrating instructional scaffolds, teacher monitoring tools, built-in formative assessments, inquiry-based learning activities, and accessibility features may further enhance teaching effectiveness and student learning.

For students. Students are encouraged to actively engage in virtual laboratory experiences by participating in scientific inquiry, collaborating with peers, asking meaningful questions, and reflecting on their learning. Taking an active role in these learning experiences may strengthen conceptual understanding, scientific reasoning, and independent learning skills.

For future researchers. Future studies may expand this line of inquiry by examining the perspectives of students, school administrators, instructional leaders, and other educational stakeholders involved in virtual laboratory instruction. Researchers may also evaluate the implementation and effectiveness of the proposed instructional guide across different educational contexts, science disciplines, and online learning environments. Additionally, employing mixed-methods, case study, or action research designs may provide broader and more comprehensive insights into virtual laboratory instruction and related pedagogical practices.

REFERENCES

Alqallaf, F. (2025). *Pre-service teachers' experiences with virtual chemistry laboratories: Engagement and challenges. Journal of Science Teacher Education, 36*(1), 55–72. *(Verify publication details.)*

Anselmo, M., Rivera, P., & Chikonde, L. (2024). *Equity and access in online laboratories: Perspectives from under-resourced schools. International Journal of Educational Technology in Higher Education, 21*(4), 1–17. *(Verify publication details.)*

Colaizzi, P. F. (1978). Psychological research as the phenomenologist views it. In R. Valle & M. King (Eds.), *Existential-phenomenological alternatives for psychology* (pp. 48–71). Oxford University Press.

Creswell, J. W., & Poth, C. N. (2024). *Qualitative inquiry and research design: Choosing among five approaches* (5th ed.). SAGE Publications.

Garrison, D. R., Anderson, T., & Archer, W. (2000). Critical inquiry in a text-based environment: Computer conferencing in higher education. *The Internet and Higher Education, 2*(2–3), 87–105. https://doi.org/10.1016/S1096-7516(00)00016-6

Graham, C. R., Borup, J., Short, C. R., & Archambault, L. (2023). *K–12 online and blended learning research: Trends and implications for practice. Online Learning Journal, 27*(1), 1–20. *(Verify publication details.)*

Grammens, T., Van Keer, H., & Depaepe, F. (2024). *Virtual laboratory implementation and inquiry-based science instruction in online learning environments. Journal of Science Education and Technology, 33*(2), 145–161. *(Verify publication details.)*

Kim, J., Park, Y., & Lim, K. (2022). *Teaching, social, and cognitive presence in online science learning environments. Computers & Education, 181*, Article 104458. *(Verify DOI if available.)*

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry.* SAGE Publications.

Luo, T., Freeman, C., & Stefaniak, J. (2021). *"Like, comment, and share": Professional development through online communities of practice. Educational Technology Research and Development, 69*(2), 839–859. *(Keep only if cited in Chapter 2.)*

Makransky, G., & Petersen, G. B. (2021). The impact of immersive virtual reality on science learning: A meta-analysis. *Educational Research Review, 34*, Article 100434.

Martin, F., Polly, D., Jokiaho, A., & May, B. (2022). *Examining faculty perceptions of student engagement strategies in online learning environments. Online Learning, 26*(1), 1–23. *(Verify publication details.)*

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

National Center for Education Statistics. (2024). *Teacher shortage areas nationwide listing, 1990–1991 through 2024–2025.* https://www2.ed.gov/about/offices/list/ope/pol/tsa.html

Navarro, J., Santos, M., & Prudente, M. (2024). *Motivation and autonomy through virtual laboratories in K–12 science classrooms. Asia-Pacific Science Education, 10*(1), 57–74. *(Verify publication details.)*

Neubauer, B. E., Witkop, C. T., & Varpio, L. (2019). How phenomenology can help us learn from the experiences of others. *Perspectives on Medical Education, 8*(2), 90–97. https://doi.org/10.1007/s40037-019-0509-2

Sapriati, A., Rahmawati, Y., & Widodo, A. (2023). *Virtual laboratories and conceptual understanding in science education: A systematic review. Journal of Science Learning, 6*(3), 221–236. *(Verify publication details.)*

Santos, M., & Prudente, M. (2022). *Virtual laboratories as meaningful alternatives for scientific investigations in online science education. International Journal of Instruction, 15*(4), 511–528. *(Verify publication details.)*

Shambare, R., & Jita, T. (2024). *Accessibility and equity considerations in technology-mediated laboratory instruction. African Journal of Research in Mathematics, Science and Technology Education, 28*(2), 184–197. *(Verify publication details.)*

Shambare, R., & Jita, T. (2025). *Teachers' perceptions and adoption of virtual laboratories in resource-limited science classrooms. Journal of Science Education and Technology, 34*(1), 88–103. *(Verify publication details.)*

Wahyudi, A. (2025). *Opportunities and limitations of virtual laboratories in online science learning environments. Journal of Educational Technology Systems, 53*(1), 43–60. *(Verify publication details.)*