An International Journal of
ISLAMIC AND SOCIAL SCIENCES

PAKISTAN ISLAMICUS

(An International Journal of Islamic and Social Sciences)

October-December, 2025, Volume:05, Issue:04 Pages:07-17

Journal Website: https://pakistanislamicus.com/index.php/home

Publisher Website: https://www.mircpk.net

BEYOND THE TEXTBOOK: A REFLECTIVE JOURNEY ON USING EXPERIMENTAL PEDAGOGY FOR TEACHING THE CONCEPT OF CHEMICAL EQUILIBRIUM IN THE PAKISTANI CONTEXT

Afreen Kanwal[1]; Dr Asra Mustafa[2]; Professor Dr Muhammad Yousuf Sharjeel[3]

[1] Lead Specialist, Aga Khan University-Examination Board, Karachi & MPhil Scholar College of Education, Faculty of Liberal Art and Human Sciences, Ziauddin University, Karachi, Sindh, Pakistan.

[2] Assistant Professor, Department of Chemistry, Federal Urdu University for Arts, Science and Technology, Gulshan-e-Iqbal Campus, Karachi, Sindh, Pakistan.

[3] Director Postgraduate Studies, College of Education, Faculty of Liberal Art and Human Sciences, Ziauddin University, Karachi, Sindh, Pakistan.

HEC -Y- Category HJRS

ARTICLE INFO

Article History:

Received:	September 12, 2025
Revised:	October 05, 2025
Accepted:	October 08, 2025
Available Online:	October 10, 2025

Keywords:

Chemical Equilibrium
Teacher Development
Le Chatelier's Principle
Qualitative Research, Pedagogical Journey
Experiential Learning, Co-investigators

Funding:

This research journal (PIIJISS) doesn't receive any specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

This qualitative study explores the impact of a teacher development workshop on the use of experiments to teach the challenging concept of chemical equilibrium in resource-constrained Pakistani classrooms. Grounded in a constructivist framework, the two-day workshop equipped 28 secondary chemistry teachers from diverse regions with hands-on strategies, including simple demonstrations, worksheets, and simulations for illustrating Le Chatelier's principle. One-year post-intervention, 23 teachers (82% of participants) were interviewed to assess implementation. The findings show a high adoption rate, with 78% of respondents successfully integrating these experiential methods. Teachers reported a profound transformation in classroom dynamics: student engagement and curiosity increased markedly as abstract concepts became visually tangible through activities like colour-change experiments. This shift positioned students as active investigators and co-learners, improving conceptual understanding and academic performance. However, the implementation journey was significantly challenged by systemic barriers, primarily severe resource scarcity, time constraints due to a crowded curriculum, and large class sizes. Teachers demonstrated notable resilience and agency in adapting the strategies to navigate these constraints. The study concludes that targeted professional development can catalyse meaningful pedagogical change even in difficult contexts. It recommends systemic support through continuous teacher training, provision of standardized low-cost laboratory kits, and alignment of curriculum and assessment with inquiry-based learning to sustain a culture of experiential, dialogic science education.

Corresponding Author's Email: **muhammad.sharjeel@zu.edu.pk**

INTRODUCTION

The Silent Challenge in Our Classrooms

At secondary-level school, teaching the concept of chemical equilibrium is difficult as compared to other concepts of chemistry (Tyson et al., 1999). This is because it expects students to comprehend invisible processes that appear static while being dynamically active (Van Driel et al., 1998). Compared to chemical equilibrium, students find concepts such as physical changes (e.g. melting, boiling and sublimation), chemical changes (e.g. neutralisation, combustion and addition), states of matter, elements, compounds and mixtures, and solution and solubility much easier to understand. Students grasp these concepts quickly because they are observable in their daily life, making learning more concrete and relatable.

Unfortunately, in many developing countries like Pakistan, the concept of chemical equilibrium is taught through traditional, lecture-based method, which makes the classroom environment dull and monotonous for both teachers and students. It is just like explaining colours to a child who has never seen them before. This research has evolved from the experience of shared professional frustration where teachers fail to make students understand the abstract symbol of a reversible reaction ($\rightleftharpoons$), followed by the Le Chatelier's principle that governs reactions at equilibrium. In Pakistan, these theoretical complications do not stand-alone. They are coupled with significant structural constraints, including large class sizes, inadequate laboratory facilities, lack of equipment, a textbook-based standardised assessment, and insufficient teacher training. In such an environment, teachers ensure algorithmic problem solving and rote memorisation of principles, without improving comprehension of the underlying particle dynamics (Gkitzia et al., 2020). This practice helps students to perform better in examinations based on superficial learning experience but fails to nurture their deep conceptual understanding, which is necessary for scientific literacy. Consequently, they perceive chemistry to be a collection of disconnected facts rather than a coherent, explanatory science. This is true: How can students sincerely comprehend a concept they have never seen, touched, or experienced?

A silent build-up of frustration was observed among chemistry teachers in school visits across different regions of Pakistan. When inquired, they shared their wish to kindle scientific curiosity among students, but their hands and minds faced formidable barriers like time, assessments, and scarce resources. Most teachers feared teaching chemical equilibrium because of consistent student disengagement. Consequently, students' performances remained poor despite teachers' persistent efforts. Understanding these concerns, the teacher support department of a non-profit organisation designed a two-day professional development workshop, aiming to empower chemistry teachers to adapt pedagogical approaches beyond traditional and textbook-centric instructions. Based on constructivist learning theories, which enable learners to acquire knowledge through experience and reflection (Piaget, 1970; Vygotsky, 1978), the workshop introduced simple, laboratory experiments and demonstrations to enable students to construct mental models of sub-microscopic processes occurring in macroscopic phenomena, bridging conceptual understanding of chemical equilibrium. This intervention was to make the invisible visible, transforming abstract discussions about molecular collisions and energy into a tangible observation of a colour change, a precipitate formation, or a temperature-pressure shift. Hence, it was re-imagining classrooms as mini laboratories for investigation and discourse.

This phenomenological, qualitative study was conducted one-year post-intervention to record the lived experiences of the teachers who attended the workshop. The purpose of the inquiry was to understand how well the pedagogical change was implemented in resource-limited settings. Rather than acquiring numerical data, understanding the depth of teachers' experiences was preferred. This explicitly helped in understanding both victories like during experimentation, a student exclaimed, "Oh, I see it!"; and challenges, which included lack of basic chemicals or the fear of extensive syllabus coverage. Following are the research questions:

1. What is the rate of implementation of experimental techniques for teaching chemical equilibrium among teachers one year after their participation in a specialized development workshop?
2. What are the perceived impacts of this experimental approach on student engagement and understanding, as reported by the teachers?

Based on these questions, this study aims to contribute a nuanced understanding that empowering teachers through targeted training can serve as a catalyst for pedagogical change. Moreover, the pedagogical intervention transformed teaching of chemical equilibrium from a passive, abstract exercise to an active, inquiry-based, and meaningful learning experience.

LITERATURE REVIEW

The section focuses on three key areas: the conceptual hurdle associated with chemical equilibrium, the role of practical work in science education, and transformative role of teachers in implementing pedagogical innovations, that form the theoretical and empirical foundation for the research.

The Conceptual Hurdle of Chemical Equilibrium

In the literature focusing science education, the comprehension of chemical equilibrium is recorded as a challenge for secondary-level students (Chandrasegaran et al., 2007; Özmen, 2008). The difficulty occurs due to strong and deeply held misconceptions. Students often struggle in making mental models of invisible, dynamic processes. They fail to make core cognitive shift from a linear, deterministic view of chemical reactions to a systemic understanding of dynamic macroscopic phenomena involving molecular level interactions (Tyson et al., 1999). Students interpret equilibrium as static – where reactions cease, rather than a dynamic process in which the forward and reverse reactions proceed at equal rates (Banerjee, 1991; Van Driel et al., 1998). This is built upon the belief that the concentrations of reactants and products must be equal at equilibrium. Hence, students can solve problems but are unable to explain the logics behind their answers (Voska & Heikkinen, 2000). Without a conceptual grasp of the dynamic nature of equilibrium, these basic misunderstandings directly influence students' ability to meaningfully apply Le Chatelier's principle in real-world contexts and thus, leads to rote memorisation of algorithmic procedures. Students superficially learn to predict the direction of shift without understanding the underlying principle. For example, students regurgitate as a fact "if you add A, the system shifts to consume A," but fail to explain the reason that this happens because the system shows a shift in the position of the equilibrium to counteract the stress through a change in the relative rates of the forward and reverse reactions (Quílez-Pardo & Solaz-Portolés, 1995). This may enable students to solve standard textbook problems based on rote-memorised rules but they remain weak at rationalising concepts and applying their knowledge in novel or real-world contexts. Literature review indicates that traditional, lecture-based pedagogies often build misconceptions by prioritising symbolic representations and algorithmic problem solving over conceptual learning (Kousathana & Tsaparlis, 2002). This practice of traditional instruction often fails to facilitate students in constructing logical mental models of dynamic processes, leading them to produce simplistic, often absurd explanations.

The Role of Practical Work in Science Education

The pedagogical intervention in this research is based on the principles of constructivist learning theory, which focuses on the notion that learners actively build understanding through experience and reflection, rather than being passive recipient of knowledge (Dewey, 1938; Piaget, 1970). Considering this framework, the role of a teacher transforms from a "sage on the stage" to a "guide on the side." This makes them responsible for creating experiences that encounter prevailing notions and enable students to construct more logical mental models.

Experiential learning gives the "concrete experience" that aligns with Kolb's (2014) learning cycle. It supports in understanding the abstract domain of chemical equilibrium by creating a bridge between unobservable molecular processes and tangible reality. The change in colours from pink to deep blue on the addition of HCl to the cobalt chloride system or observing the chromate (yellow) – dichromate (orange) equilibrium shift with the change in pH not only produces the eureka effect but helps anchor the abstract principle of Le Chatelier in a physical reality. These sensory engagements like colour changes, and temperature variations make invisible dynamic processes visible, creating memorable moments and providing a shared phenomenological basis for classroom discourse (Hofstein & Lunetta, 2004).

The effectiveness of experiential learning is well supported empirically. Research suggests that students when engaged in laboratory work and hands-on demonstrations, they show extraordinary conceptual understanding, which retains in minds for a significant period compared to those concepts that are only taught through lecture-based methods (Abrahams & Millar, 2008). Experiments play a fundamental role in scientific inquiry, education, and practical problem solving. They facilitate the direct observation of phenomena, testing of hypothesis; support the formation of accurate concepts, and strengthen scientific reasoning. However, experimentation is not dependent on sophisticated equipment and a well-equipped laboratory. Concepts can be tested using simple, low-cost material, ensuring that the process significantly enhances student motivation, curiosity, and conceptual grasp – an insight that is especially relevant in resource-constrained environments.

Transformative Role of Teachers

Effective pedagogical strategies play a significant role in reforms; however, transformations cannot occur without teachers who are the central agent of implementation. Their role is instrumental in bringing pedagogical change, transforming classrooms, schools and societies at large. Without their buy-in, competence, and commitment, even the most well-designed innovations fail at the doorstep of a classroom (Fullan, 2016). The change within the evolving educational landscape depends on teachers' pre-existing beliefs and attitudes, which shape their interpretation and implementation of new methods (Fang, 1996). Continuous professional development (PD) plays a crucial role in motivating and supporting teachers to experiment new methods. They provide ongoing, practical learning opportunities to help teachers improve their knowledge, skills and attitudes, ultimately enhancing students' learning outcomes. As emphasised by Guskey (2002) and Desimone (2009), PD should not be a passive event, comprising of a single, isolated workshop. It should be an active, ongoing learning process focussing on content, collaboration among peers and coherence with policies, providing teachers with practical, manageable strategies along with the underlying rationale for a significant period. In science education, PD emphasises hands-on experimentation that has proven to be more effective and successful in changing classroom practices. Such sessions develop both teachers' confidence and conceptual understanding, leading to effective and efficient teaching practices (Bucat, 2004).

In Pakistan, professional development of teachers varies significantly due to reasons like lack of consistent funding, disconnection from classroom realities, limited follow-up support and more. This research aims to address this gap by examining the long-term impact of a certain pedagogical intervention one-year after the professional development session. This training workshop was deliberately designed to empower teachers by providing them hands-on experience of experiments before they implement the same in their classrooms. The core principle was when teachers personally experience the technique and observe its power through positive student learning outcomes, the chances of the techniques' adoption increases. Hence, it fosters a growth mindset, transforming beliefs and developing autonomy to act as an agent of change.

Bridging the Gap: From Theoretical Ideal to Lived Practice

Western literature has predominantly established the theoretical merits of inquiry-based and experiential learning; however, there remains a significant gap in understanding the implementation of these pedagogical approaches in resource-constrained contexts. The aim of this study is to address this gap by providing in-depth, reflective insights into the lived experiences (perceptions, moments of joy, and resolve in time of constraints) of Pakistani teachers who practiced inquiry-based and experiential learning approaches in their classrooms.

Sadly, in Pakistan, the integration of hands-on learning in real classroom contexts faces multiple systemic barriers. This is based on a study that reveals resource constraints – lack of basic chemicals, non-functional laboratories, incompetent teachers and time limitations – severely impede experimental work (Rehman et al., 2025). These constraints are often intensified by teachers' fear of losing instructional time, thus become overburdened with extensive syllabus coverage. Another attitudinal barrier that overshadows teachers' enthusiasm is the concern regarding students' safety when managing experiments in overcrowded classrooms. This is well supported by studies from South Asia that document that no matter how much the teachers value inquiry-based methods, their implementation remains inconsistent due to lack of active and sustained institutional support (Farooq & Shah, 2008).

Hence, these factors validate that pedagogical intervention is more than a technical exercise. It is a process deeply influenced by context. Here, the concern is not whether inquiry-based learning is effective in conceptualisation of theory, but how its implementation can be made feasible, sustainable, and authentically aligned with the dynamics of diverse classrooms. In essence, this research underscores a vital perspective on the relationship among teacher agency, pedagogical innovation, and systemic constraints by exploring the attempts of teachers to integrate simple experiments in a period of one-year post-training. The study identified key themes that are central to understanding educational change in the Global South.

METHODOLOGY

Research Paradigm and Design

This study employed a qualitative, phenomenological research design to explore the in-depth insights into "lived experiences" of teachers who integrated experimental pedagogy into their practice (Creswell & Poth, 2018). The purpose was to study the impact of a pedagogical intervention over a one-year period, including teacher perceptions, motivation, classroom dynamics, and student engagement as understood through the participants' lived experiences (Merriam & Tisdell, 2016). The target was not to measure frequency but to richly explore teachers' passion and contributions in trying out the new approaches in their classrooms. This included triumphs, challenges, and reflective insights to describe their learning experience.

The Intervention: A Practical Workshop on Experimental Pedagogy

The intervention was a two-day intensive workshop on chemical equilibrium that moved quickly from theoretical discussion to hands-on, experiential learning. It was organised by the teacher support department of a non-profit organisation. This institution is dedicated to promoting conceptual understanding and inquiry-based learning among students at the national level. Twenty-eight chemistry teachers of secondary and higher secondary school representing diverse regions of Pakistan (Sindh, Punjab, and Gilgit-Baltistan) participated in the workshop. This diversity ensured that the findings reflect a wide range of educational perspectives, from well-resourced urban private schools to potentially under-resourced rural institutions.

The core workshop activities involved theoretical refresher of the concept of chemical equilibrium and Le Chatelier's principle, emphasising common student misconceptions, followed by performance of a series of simple yet effective, low-cost equilibrium experiments demonstrating Le Chatelier's principle (Figure 1). These included:

- **The Cobalt Chloride Equilibrium System:** Detecting the colour shift between $[Co(H_2O)_6]^{2+}$ (pink) and $[CoCl_4]^{2-}$ (blue) due to changes in concentration and temperature (Figure 1a).
- **The Chromate-Dichromate Equilibrium System:** Witnessing the equilibrium shift between CrO_4^{2-} (yellow) and $Cr_2O_7^{2-}$ (orange) due to the addition of acid and base (Figure 1b).
- **The Iron Thiocyanate Equilibrium System:** Visualising the change in colour intensity of $[Fe(SCN)]^{2+}$ (blood-red) due to the addition of ions, complexing agents, or by changing temperature (Figure 1c).

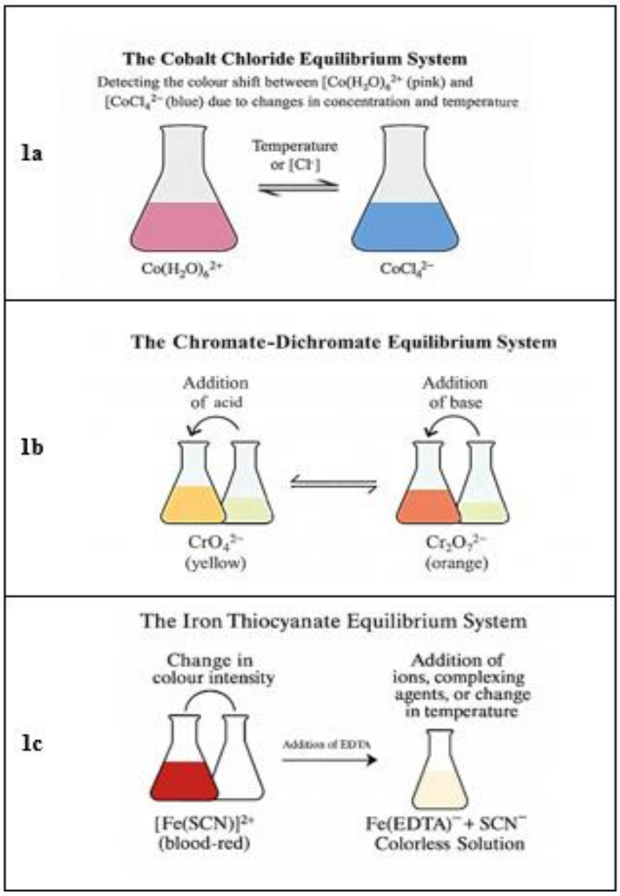

Figure 1: Effective, Low-Cost Equilibrium Experiments Demonstrating Le Chatelier's Principle

Moreover, teachers were provided with ready-to-use worksheets alongside videos and simulations that linked experimental observations to theoretical explanations. Timeslots were dedicated to have pedagogical discussions, including how to integrate these experiments into the standard curriculum, manage classroom logistics, and anticipate and address student questions through the prediction-observation-explanation cycle. The purpose was not only to build technical skills but also to model an engaged, dialogic classroom environment. Teachers were explicitly advised and encouraged to implement these experiments, worksheets, videos and simulations in their own classrooms during the upcoming academic year.

Participants and Sampling

The population for this study included all trained participants (N=28) who attended the workshop. One-year after the workshop, through purposive sampling, a wide range of instructional realities was captured across Pakistan. Out of 28 trained participants, 23 teachers (82%) were successfully contacted, and they willingly agreed to participate in the structured telephonic interview. The high engagement rate of teachers revealed their continuous interest in the innovative teaching methodologies for chemistry shared in the workshop. Figure 2 effectively highlights the significantly higher number of teachers who continued their engagement with the study one year after the workshop.

Data Collection and Instrument

A follow-up data collection exercise was conducted one-year after the workshop – a timeframe that allowed substantial period for pedagogical implementation. The primary data was gathered through structured telephonic interviews because it was practical to reach a geographically dispersed group of teachers in a cost-effective manner. Of 28, 23 teachers shared the lived experience in interviews that lasted for 10-30 minutes. The interview protocol consisted of both closed and open-ended questions. There were three closed ended (Yes/No) questions designed to elicit the implementation rates, student engagement, and perceived effectiveness. Where the answer was 'No', probing questions were used to elicit reasons (e.g., didn't teach the topic, lack of resources, time constraints). These were then followed by a single, open-ended narrative prompt: "How was the experience of practicing the experiments related to chemical equilibrium and Le Chatelier's principle in the classroom? (Your answer should include successes or challenges faced in experimentation.)". This prompt was intentionally broad to capture real classroom dynamics like how students reacted to experimental lessons (e.g., levels of engagement, questions asked, apparent understanding), feasibility of implementation (e.g., successes and challenges encountered during implementation). During interviews, initial responses of teachers played as springboard for deeper conversations, further prompting for specific anecdotes (e.g., availability of chemicals, time management, support from school administration). Interviews were bilingual giving ease to teachers to share their stories and these were transcribed verbatim, preserving the authentic mix of Urdu and English used by the participants.

DATA ANALYSIS

The teacher narratives were analysed using Braun and Clarke's (2006) six-step framework for inductive thematic analysis. This involved:

1. The interview transcripts were read repeatedly to achieve immersion and familiarity.
2. Initial codes were generated to categorise the information (e.g., "student wonder," "resource scarcity," "colour as an anchor," "shifts in teacher confidence").
3. Potential themes were developed by collating the codes. For instance, comments about students "asking more questions" were grouped under the theme "Increased Student Engagement," while mentions of "no chemicals available" were categorised under "Barrier: Lack of Resources."
4. Themes were rigorously reviewed and refined against the coded data and the entire dataset (e.g., Barrier: Lack of Resources was refined to Navigating the Tyranny of Constraints).
5. This step involved the defining and naming of themes, confirming that the organisation of information makes sense.
6. Finally, the thematic analysis was clearly written, including quotes from the data and discussing the broader implications of the findings.

This iterative process validated that the identified themes accurately reflect the participants' lived experiences and perspectives. The final thematic structure, including themes like increased student engagement, a chain reaction of curiosity, the teacher's metamorphosis, navigating the tyranny of constraints, improved academic performance, and a legacy beyond the lesson, frames and organizes the findings presented in the next section.

Ethical Considerations and Researcher Positionality

The study design and its implementation followed strict ethical guidelines throughout. Trained teachers had the freedom to participate voluntarily without any imposition from the facilitator (researcher). Their anonymity and confidentiality were guaranteed. Additionally, the research data was used solely for academic and professional development purposes. Reflexivity was taken into consideration while interacting with participants, recording their lived experiences and analysing the data. Teachers were interviewed with a sense of trust that their transparent insights of triumphs and challenges ensure ethical rigor and depth, while balancing the researcher's interpretive role with the participants' lived experiences.

RESULTS

The analysis of teacher narratives captured through telephonic interviews is documented below. The findings reveal that the integration of simple experiments transformed teaching and learning of chemical equilibrium. The five central themes clearly depict that this transformation was both intellectually rewarding as well as logistically challenging.

Descriptive Overview: A Strong Foundation for Change

After one-year post-intervention (Figure 2), 23 out of 28 trained teachers participated in the follow-up session that depicts 82% response rate, providing a clear view of adoption and initial reception:

- **Implementation:** The data represents an implementation rate of 78% (n=18) among the respondents, who were successful in performing workshop experiments in their classrooms.
- **Non-Implementation:** The remaining 22% (n=5) did not implement the method as they had not been assigned to teach the topic of chemical equilibrium that academic year.
- **Student Engagement & Perceived Efficacy:** Teachers who successfully implemented reported that their students enjoyed the activities with enthusiasm and the integration of experiments made the understanding of chemical equilibrium easy.

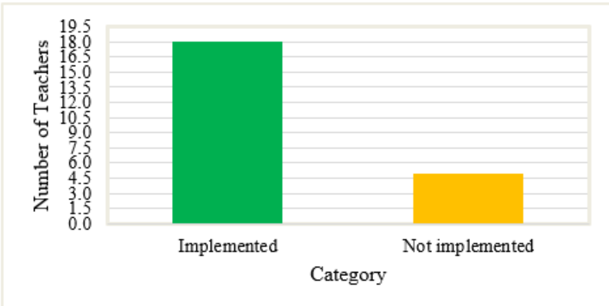

Figure 2: Implementation of Workshop (One-Year Post-Intervention)

None of the teachers cited a lack of willingness or a negative perception of the method as their primary reason for non-implementation. This strong baseline data is followed by nuanced thematic findings as under.

Thematic Findings: The Heart of the Transformation

Theme 1: Increased Student Engagement

The frequently reported phrases were "students were fascinated by colour changes," "it broke the monotony of the lecture" and most importantly "the class came alive". The dominant observation was that students were more attentive and interested in experimental demonstrations, which played the key role of "cognitive anchor", enabling students to grasp the dynamic, molecular-level processes easily. A teacher reported: "Usually, when I begin this chapter, I observe pale faces with a notion – please skip this topic. But this time, seeing the colour change from yellow to orange on addition of acid to the chromate solution, 'a collective gasp' with an understanding of the reason – 'why it happened' changed the classroom dynamics." This sensory engagement promoted shared investigation making the classroom environment interactive. Another teacher reported, "The experiments provided a concrete reference point that enabled students to build an accurate mental model of the dynamic processes."

Theme 2: A Chain Reaction of Curiosity

The experiments acted as a catalyst, transforming students from passive recipients of instruction to active investigators, understanding the underlying causes. Teachers reported a fundamental change in students' energy level with a remarkable shift in classroom dynamics. One teacher noted, "Experiments triggered students' curiosity, and they started asking more about the concept – 'Sir, what if we add more water?' 'Why did it turn pink again when heated?' and 'Can we repeat the same experiment using an acid or a base?'" This active, dialogic engagement was well described by a teacher who stated "Reading text from books is boring, while understanding through experiments is exciting."

Theme 3: The Teacher's Metamorphosis

A significant outcome was the pedagogical shift that enabled teachers in transitioning from being "the sage on the stage" to a "a guide on the side." A veteran teacher reported, "I have always been a depositor – transferring knowledge when teaching chemical equilibrium. But this academic session, my role changed. I set up the experiment, posed probing questions, and allowed chemistry to speak for itself. I was a co-investigator, learning alongside students." This theme exemplifies that pedagogical intervention facilitated teachers in exploring their own sense of purpose and passion, optimistically changing their professional self-concept.

Theme 4: Navigating the Tyranny of Constraints

Despite positive outcomes, the path was full of practical challenges. The extensive curriculum coverage caused time constraints. It made teachers feel that conducting experiments during the session was time-consuming compared to lecturing from the book, especially when preparing for board examinations. A few teachers with very large classes (over 50 students) expressed concerns about classroom management during practical activities and faced challenges in ensuring that all students see demonstrations clearly. Amongst all, the most prominent barrier was the lack of resources – a "tyranny of constraints" that tested teachers' determination. They stated, "The cobalt chloride experiment is easy but school doesn't have cobalt chloride salt in the laboratory." Teacher had to arrange the salt from the store themselves. Another teacher exclaimed, "There is no refrigerator in the school to access cold water or ice." Irrespective of all these barriers, teachers demonstrated remarkable resilience and creativity. They used worksheets, videos and simulations shared during the two-day workshop as evident in teachers' narratives to facilitate students in constructing mental models of invisible dynamic processes. The students thoroughly enjoyed the activities which proved that the pedagogical innovation was not only about hands-on-execution but embedded skilful adaptation of core experiential principles to address contextual constraints.

Theme 5: Improved Academic Performance and A Legacy Beyond the Lesson

Several teachers anecdotally reported better performances of students in class tests and examinations on the topic of chemical equilibrium after exposure to experiential learning through experiments. It strengthened their belief that visual and experiential learning ensures long-term retention and application of concepts. Moreover, the most amazing finding was the creation of a new classroom culture of expectation, inquiry and evidence-based reasoning beyond the specific topic of chemical equilibrium. A teacher shared the ripple effect, "My students now ask for every topic, 'Maám, is there an experiment for this?'" This pedagogical change encouraged inquiry-based learning across the curriculum, suggesting that the investment in a single, challenging and complex topic can lead to dividends throughout the students' theoretical experience.

DISCUSSION

Based on theoretical framework of constructivism and experiential learning, this section interprets the findings of the research that a modest pedagogical intervention can humanize science education even within challenging contexts. This study yields a compelling narrative. The high implementation rate (78%) shows that the introduction of simple, hands-on experiments served as a powerful catalyst. Teachers' willingness to adopt innovative pedagogical methods brought a positive change in the teaching and learning of chemical equilibrium.

The Experiential Bridge: From Abstract Theory to Tangible Understanding

The experiments played an important role of "cognitive bridge," making the invisible dynamics of chemical equilibrium intellectually and visually tangible. The teacher's observation of the "collective gasp" during a colour change exemplifies the "concrete experience" stage of Kolb's (2014) learning cycle. The use of senses during experimentation alongside 'what', 'how' and 'why' on every result proves that constructivist theory is applicable in building logical mental models (Dewey, 1938). This enabled students to overcome misconceptions and internalise the dynamic nature of reversible reactions by observing the application of Le Chatelier's principle, where colours represent system shift to re-establish equilibrium (Banerjee, 1991). The study aligns with global discoveries on the impact of visualizations (Hofstein & Lunetta, 2004) but gains insight into a context where abstract, textbook-driven instruction is the norm. The phenomenological experience of experiments helped in meaningful construction of knowledge beyond illustrating a principle.

A Shift in Classroom Culture: Igniting Curiosity and Dialogic Learning

Learning through experiments transformed the classroom dynamics beyond clarifying concepts. It promoted student engagement and enabled them to question, "What if we add more?" that signals a fundamental shift from passive reception to active inquiry. This finding directly refers to the passive, lecture-centric pedagogical approach often found in many science classrooms in Pakistan, largely due to systemic barriers like inadequate resources or large class sizes (Rehman et al., 2025). The experiential learning created a dialogic and evidence-based learning environment in the chemistry classroom. The students' active engagement in the learning process was effectively summarised in one of the teacher's quotes: 'Reading text from books was boring, whereas its comprehension through experiments was fun.' This 'fun' didn't arouse from easy amusement but came into existence because students challenged their deep thinking by asking and answering questions, exploring ideas and valuing the process of discovery. This pedagogical shift is crucial for educational systems implementing modern curricula, including Pakistan's competency-based initiatives, as it fosters higher-order thinking skills and cultivates critical thinking and analytical abilities.

The Teacher's Metamorphosis: Renewed Identity and Agency

The major finding of this research was the powerful impact on the teachers themselves. They transformed from the "sage on the stage" to a "guide on the side", which clearly highlights that effective professional development (PD) emphasises a holistic approach beyond mere technical skills acquisition (Guskey, 2002). The hands-on experience of the workshop played a significant role in this transformation. By experiencing how students learn, teachers not only build their competence (skills and knowledge) but also developed conviction. They refined their instructional strategies according to students' needs and with a firm belief in their ability to improve student outcomes. Hence, they developed personal mastery that proved significant in navigating real-world constraints.

Navigating Limitations with Resilience

The teachers and students faced overwhelming barriers that felt restrictive and potentially oppressive such as lack of chemicals, equipment, and time. This finding aligns perfectly with the literature that stresses implementation barriers in resource-constrained environments (Farooq & Shah, 2008). However, it includes a fundamental nuance that despite limitations, teachers did not simply surrender. They came up with alternatives and used detailed descriptions, diagrams/ visual models, videos and simulations for experiential learning. This adaptive resilience is synonymous with pedagogical content knowledge, which is often undervalued or ignored in educational practice and professional development. It establishes that the core principle of experiential learning, is connecting theoretical knowledge to concrete experiences. This can be achieved through various methods, ranging from physical, hands-on activities to purely intellectual and imaginative experiments (mental models). The study clearly indicates that professional development should equip and empower teachers with the alternative strategies alongside ideal-model experiments to be able to work in real-world contexts.

RECOMMENDATIONS

Based on the understanding gained about experiential learning and its associated challenges, the following recommendations are proposed for key stakeholders to create and sustain a supportive ecosystem for a hands-on approach in chemistry education.

1. **For Policymakers, Curriculum Boards, and School Administrators:**
    - **Standardize Resource Provision:** Allocate adequate funds for resources and provide portable, low-cost laboratory kits for core chemistry concepts, especially for rural and under-resourced schools. Curriculum boards should also develop and disseminate a standardized list of essential equipment and chemicals. They should also include alternative experiments as per varied contexts.
    - **Establish Continuous Professional Development:** Professional development should not be a one-time activity; rather, it should be a continuous cycle that includes follow-up sessions, collaborative networks, and supportive visits to classrooms. This ongoing process helps in maintaining the momentum to improve skills and knowledge and timely troubleshoot challenges.
    - **Align Assessment, Curriculum and Pedagogy:** Constructive alignment between content and instructional strategies (like experiments, inquiry-based tasks, or guided discussions) directly support the intended learning outcomes, builds conceptual understanding and evidence-based reasoning, while assessments precisely measure the student achievement of those outcomes.
2. **For Teacher Educators and Training Institutions:**
    - **Demonstrate Experiential Pedagogy:** Design practical, collaborative professional development programmes that promote a student-centred and conducive learning environment. The purpose of these programmes should not only be to discuss experiments with teachers but to actively engage them in performing those experiments. This hands-on participation will familiarise them with the techniques, making it easier to adopt such strategies in their own classrooms.
    - **Incorporate "Economical Science" Training:** Design trainings that equip teachers with essential skills of creating and implementing effective experiments using low-cost, indigenous resources. These trainings will help teachers in building their confidence and resilience towards change despite limited resources.
    - **Innovate Guides:** Aligned with the chemistry curriculum, develop and share structured guides for performing experiments, including detailed materials list, step-by-step procedures, safety precautions, integration of skills and probing viva questions for formative and summative assessment. These ready-made guides will save the preparation time and encourage teachers to efficiently facilitate inquiry-based learning in their classrooms, which enhances student engagement.
3. **For Teachers (Our Fellow Travellers on This Journey):**
    - **Implement a Thoughtful Approach:** Initiate the new academic session by incorporating one or two essential experiments in the annual teaching plan. Ensure to record the learning experiences, highlighting success stories, students' reactions and associated challenges. Develop a community of practice with likeminded teachers, where you can share these reflections for constructive feedback and improvement.
    - **Cherish Student-Centered Breakthrough:** Adopt the role of a "guide on the side" rather than a "sage on the stage". Integrate experiments to probe questions and facilitate curiosity, trusting the process of discovery to build depth over breadth.
    - **Develop Professional Community:** The best resource for every teacher is the collaborative learning communities – a platform for sharing materials, strategies, and successes with peers. These communities empower teachers to design effective teaching and learning strategies, discuss challenges and explore ways to address constraints by advocating collectively the request for essential resources and support from the management.

CONCLUSION

A shared observation initiated the research to address the challenge in comprehending the complex dynamics of chemical equilibrium for teachers and students. The findings reaffirm that using experiments to teach chemical equilibrium is not just a pedagogical shift; rather it stimulates a systemic change in chemistry classrooms. These strategies facilitate students to connect abstract concepts to real-world contexts by promoting a culture of curiosity and critical thinking. They also empower teachers rebuild confidence and a sense of control in their teaching. A constructive outcome was that students started exploring opportunities to experiment with chemistry concepts beyond chemical equilibrium. They started asking, "Is there an experiment for this?" across other chemistry topics. The hands-on-approach worked as a ripple effect, encouraging the growth mindset of inquiry, dialogues and evidence-based reasoning across chemistry curriculum. This experiential approach inducted a progressive culture, where students and teachers became co-investigators, actively testing ideas and connecting theory with practice.

Findings exhibit that this practical approach greatly escalated student engagement and improved conceptual understanding. Visualisation of changing colours behaved as "cognitive anchors," making otherwise invisible processes intellectually accessible. By examining how systems responded to different factors, whether a change in concentration or temperature, it became easier for the students to visualise the real application of theoretical principles. This strengthened their understanding of chemical equilibrium, enabling teachers to become effective facilitators of discovery. The pedagogical journey, however, was constrained by systemic challenges such as limited resources, large class sizes, and a content-heavy syllabus. These experiences highlight that teacher training alone cannot sustain meaningful change unless it is supported by an ecosystem that provides ongoing professional development, adequate resources and a curriculum that prioritises depth over breadth. Eventually, a classroom where a beaker changes colour becomes a space where thinking shifts. Teachers clarified a complicated topic by making the unseen visible and students' eyes sparkled with joy. Through a humanising, dialogic approach in science education, teachers also re-experienced their own passion for teaching. Hence, the wider implementation of experimental pedagogy, visual models, simulations and reasoning exercises in the field of chemistry depends on collective commitment and systemic support. Thereby, enabling every learner to experience moments when chemistry speaks for itself.

REFERENCES

Abrahams, I., & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. International journal of science education, 30(14), 1945-1969.

Banerjee, A. C. (1991). Misconceptions of students and teachers in chemical equilibrium. International journal of science education, 13(4), 487-494.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative research in psychology, 3(2), 77-101.

Bucat, R. (2004). Pedagogical content knowledge as a way forward: Applied research in chemistry education. Chemistry Education Research and Practice, 5(3), 215-228.

Chandrasegaran, A. L., Treagust, D. F., & Mocerino, M. (2007). The development of a two-tier multiple-choice diagnostic instrument for evaluating secondary school students' ability to describe and explain chemical reactions using multiple levels of representation. Chemistry Education Research and Practice, 8(3), 293-307.

Cres well, J. W., & Poth, C. N. (2018). Qualitative inquiry and research design: Choosing among five approaches (4th ed.). Sage Publications.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. Educational Researcher, 38(3), 181-199.

Dewey, J. (1938). Experience and education: Kappa Delta Pi. International Honor Society in Education.

Fang, Z. (1996). A review of research on teacher beliefs and practices. Educational Research, 38(1), 47-65.

Farooq, M. S., & Shah, S. Z. U. (2008). students' attitude towards mathematics. Pakistan Economic and Social Review, 75-83.

Fullan, M. (2016). The new meaning of educational change. Teachers college press.

Gkitzia, V., Salta, K., & Tzougraki, C. (2020). Students' competence in translating between different types of chemical representations. Chemistry Education Research and Practice, 21(1), 307-330.

Guskey, T. R. (2002). Professional development and teacher change. Teachers and Teaching, 8(3), 381-391.

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. Science Education, 88(1), 28-54.

Kolb, D. A. (2014). Experiential learning: Experience as the source of learning and development. FT press.

Kousathana, M., & Tsaparlis, G. (2002). Students' errors in solving numerical chemical equilibrium problems. Chemistry Education Research and Practice, 3(1), 5-17.

Merriam, S. B., & Tisdell, E. J. (2016). Qualitative research: A guide to design and implementation (4th ed.). Jossey-Bass.

Özmen, H. (2008). Determination of students' alternative conceptions about chemical equilibrium: A review of research and the case of Turkey. Chemistry Education Research and Practice, 9(3), 225-233.

Piaget, J. (1970). Science of education and the psychology of the child. Trans. D. Coltman. Orion Press.

Quílez-Pardo, J., & Solaz-Portolés, J. J. (1995). Students' and teachers' misapplication of Le Chatelier's principle: Implications for the teaching of chemical equilibrium. Journal of Research in Science Teaching, 32(9), 939-957.

Rehman, N., Huang, X., Mahmood, A., Abbasi, M. S., Qin, J., & Wu, W. (2025). Assessing Pakistan's readiness for STEM education: an analysis of teacher preparedness, policy frameworks, and resource availability. Humanities and Social Sciences Communications, 12(1), 1-17.

Tyson, L., Treagust, D. F., & Bucat, R. B. (1999). The complexity of teaching and learning chemical equilibrium. Journal of Chemical Education, 76(4), 554.

Van Driel, J. H., De Vos, W., Verloop, N., & Dekkers, H. (1998). Developing secondary students' conceptions of chemical reactions: The introduction of chemical equilibrium. International Journal of Science Education, 20(4), 379-392.

Voska, K. W. & Heikkinen, H. W. (2000). Identification and analysis of student conceptions used to solve chemical equilibrium problems. Journal of Research in Science Teaching, 37(2), 160-176.

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.