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INQUIRY BASED LABORATORY INSTRUCTIONS (IBLI) AS AN INNOVATIVE APPROACH TO THE TEACHING OF CHEMISTRY

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ABSTRACT

Chemistry is an experimental science in which learner connect theoretical concepts with observation, evidence, experiment and explanation for meaningful learning. Generally teaching of chemistry in many educational institutions still based on teacher centered, text book based explanation, predetermined laboratory procedures and rote memorization of concepts and reactions. Such teaching methods are not developing students' curiosity, problem solving, critical thinking, laboratory skills and conceptual understanding. Inquiry Based Laboratory Instructions (IBLI) is a learner centered approach which offers an alternative pedagogical approach by transforming the laboratory from a place of following prescribed procedures to an environment of questioning, investigation, experimentation; evidence based reasoning and scientific communication. The present study adopts a qualitative literature based conceptual research methodology to examine Inquiry Based Laboratory Instructions (IBLI) as an innovative approach to the teaching of Chemistry. Inquiry Based Laboratory Instructions grounded constructivist learning theory, experiential learning theory, discovery learning theory and scientific inquiry, it can designed inquiry based laboratory methods which promote active engagement, conceptual understanding, scientific process skills, problem-solving skill, collaboration and positive attitude towards chemistry. This study also explain need for innovative approaches in chemistry teaching with some illustrative examples such as separation of mixtures, factors affecting the rate of a chemical reaction; acids, bases and natural indicators, factors affecting solubility and electrolysis of water.

Keywords: Inquiry Based Laboratory Instructions (IBLI), Laboratory Teaching, Scientific Inquiry, Chemistry Education, Scientific Process Skills, Scientific Reasoning.

1 INTRODUCTION

Chemistry is fundamentally an experimental discipline that seeks to explain the composition, properties, structure and transformations of matter. Effective chemistry education therefore requires more than the transmission of theoretical information. Students need opportunities to observe phenomena, formulate questions, design investigations, collect

and interpret evidence and construct explanations based on their observations. Laboratory experiences have traditionally been regarded as an important component of science education because they provide opportunities to connect abstract concepts with practical experiences. Despite the importance of laboratory work, chemistry practical instruction is frequently organized around highly structured activities in which students follow predetermined instructions to obtain an expected result. In such settings, learners may focus primarily on completing procedural steps rather than understanding why an experiment is performed, how a problem can be investigated or how evidence supports a scientific explanation. When laboratory activities become routine exercises their potential to develop scientific reasoning and inquiry skills may remain underutilized. The increasing emphasis on learner centered, competency based, experiential and activity oriented education has created a need for alternative approaches to laboratory teaching. Inquiry based learning provides one such approach. Inquiry based instructions engages learners in processes that resemble important aspects of scientific practice, including questioning, investigation, evidence collection, analysis, explanation and communication. Inquiry Based Laboratory Instructions (IBLI) can be conceptualized as a pedagogical approach in which laboratory activities are deliberately designed around scientific inquiry. Instead of merely providing students with a procedure to follow, IBLI encourages them to investigate meaningful questions, make predictions, select or develop procedures, conduct experiments, analyze evidence and construct scientifically justified conclusions. The approach is particularly relevant to chemistry because many chemical concepts involve invisible or abstract processes that become more meaningful when students interact with observable evidence. For example, concepts such as chemical reactions, solubility, separation of mixtures, acids and bases, reaction rates and electrochemical processes can be explored through carefully structured inquiry activities. This study shows conceptual and pedagogical importance of IBLI.

2 THEORETICAL FRAMEWORK

The Inquiry Based Laboratory Instructions (IBLI) based on learning theories that emphasize active investigation, practical experience and meaningful engagement with scientific phenomena. It is grounded in Piaget's (1952) constructivist learning theory, which views learners as active constructors of knowledge through experience. Vygotsky's (1978) social constructivism emphasizes collaborative learning through teacher and peer interaction. Kolb's (1984) experiential learning theory emphasizes experience, reflection, conceptualization and experimentation, while Bruner's (1961) discovery learning theory supports learning through exploration, discovery and active participation. Another foundation is provided by the National Research Council's (NRC, 2000) Scientific Inquiry Framework. The NRC defines inquiry as activities such as asking questions, planning investigations, collecting and analyzing evidence, developing explanations and communicating findings. It also emphasizes that students develop a meaningful understanding of inquiry through direct experience and consistent practice, rather than simply memorizing scientific terminology or procedures. These principles are closely related to the teaching methods described in IBLI, specifically asking questions, hypothesizing, investigating, observing, analyzing evidence, explaining, communicating and reflecting. This study considers IBLI as a theory based teaching approach in which laboratory experiences serve as a means of building chemical knowledge, developing scientific process skills, strengthening conceptual understanding and promoting scientific reasoning. This framework provides a basis for examining whether inquiry based lab learning can enhance the effectiveness of chemistry teaching by combining theoretical concepts with practical investigations and evidence based learning. It also helps enhance teachers' capacity for inquiry based learning, a factor considered essential in preparing teachers for inquiry based science teaching.

3 CONCEPTUAL FRAMEWORK

The conceptual framework of the present study is based on Inquiry Based Laboratory Instructions (IBLI) as an innovative approach to the teaching of Chemistry. IBLI is conceptualized as a learner centered and inquiry oriented pedagogical approach that integrates theoretical concepts with practical laboratory experiences. This framework indicate that good chemistry learning occurs when learners actively engage in questioning, hypothesizing, experimental planning, observation, data collection, analysis, explanation, communication and reflection, rather than simply following predetermined lab procedures. In this study, IBLI represents the independent variable and the main instructional intervention. Its implementation involves structured laboratory activities through which learners investigate chemical phenomena, examine evidence and build scientific understanding through direct experience. Key aspects of IBLI include questioning, hypothesizing, investigation, experimentation, observation and measurement, evidence collection, data analysis, explanation, communication and reflection. These processes are expected to strengthen learners' active participation and scientific engagement. This framework identifies several dependent learning outcomes, including conceptual understanding, scientific reasoning, scientific process skills, laboratory competence, critical thinking, problem solving ability and the application of chemical knowledge to unfamiliar and real life situations. IBLI can also increase learners' curiosity, confidence, engagement and participation in laboratory learning. The framework further considers contextual factors that may influence the implementation and effectiveness of IBLI, including laboratory resources, teacher preparation, instructional time, institutional support, learners' prior knowledge and classroom environment. These factors can facilitate or hinder the achievement of desired learning outcomes. Thus, the conceptual

framework creates a logical relationship between IBLI; inquiry based learning processes and chemistry learning outcomes. It provides a basis for examining whether replacing predominantly procedural laboratory practices with structured inquiry-oriented experiences can enhance the effectiveness, meaningfulness, and quality of Chemistry teaching and learning.

4 LITERATURE REVIEW

Inquiry Based Laboratory Instructions (IBLI) has gained increasing attention as an innovative approach for making science learning active, meaningful and skill oriented. It provides learners with opportunities to formulate questions, investigate problems, conduct experiments, analyse evidence and construct scientific explanation. Previous research provides evidence of the effectiveness of inquiry oriented approaches. Recent research has increasingly examined inquiry-based laboratory instruction as an approach for strengthening the connection between theoretical concepts and practical experiences in Chemistry. Orosz et al. (2023) investigated guided inquiry-based learning among 88 Grade 9 students in secondary-school Chemistry. Their study developed inquiry-oriented teaching materials aimed at promoting scientific reasoning and scientific process skills. The findings indicated that guided inquiry can be implemented with students who are new to the approach when appropriate scaffolding is provided. However, students had particular difficulties formulating hypotheses, recording observations and evaluating hypotheses based on the evidence gathered. These results demonstrate the importance of structured guidance in inquiry based chemistry laboratory instruction. Another recent contribution by Wang et al. (2025) demonstrates how inquiry based learning can be integrated with technological innovations in analytical chemistry. Their study introduced an innovative laboratory activity combining inquiry based learning using photoelectric technology and cerium analysis. This approach demonstrates how real analytical chemistry problems and modern laboratory technology can be incorporated into inquiry oriented instruction, taking laboratory learning beyond routine procedural exercises. Twizeyimana and Shiramunda (2026) also provided strong quantitative evidence through a meta-analysis of 10 empirical studies published between 2018 and 2024. Their results showed that inquiry based chemistry laboratory instruction led to significantly greater conceptual understanding than traditional laboratory approaches, with a pooled Hedges' g of 0.71. The authors also observed slight variation across studies, suggesting that the effects of inquiry based lab instruction may vary depending on instructional design, educational level, context and implementation conditions. Kantor and Konstantopoulos (2009) reported that when inquiry based curriculums were supported by good teacher knowledge and teaching methods, they improved science achievement among minority students. Blanchard et al. (2010) found that guided inquiry lab activities led to greater learning and retention of concepts than traditional verification activities. Research involving prospective teachers also found positive results. Ozgelen et al. (2013) highlighted improvements in understanding the nature of science through structured and reflective inquiry, while Yakar and Baykara (2013) reported gains in scientific process skills, creative thinking and attitudes towards experimentation. Irwanto et al. (2019) further demonstrated improvements in critical thinking among prospective teachers. Research has also examined laboratory skills and self-efficacy. Eymur (2018) associated Argument-Driven Inquiry with improvements in laboratory skills and self-efficacy, while Cetin (2020, 2021) reported positive developments in students' understanding of scientific inquiry. Hernandez et al. (2020) highlighted increased participation among underrepresented learners in guided inquiry environments. Technology supported inquiry through virtual and online laboratories has further expanded opportunities for scientific reasoning and conceptual learning (Nedungadi et al., 2015; Mutlu & Şeşen, 2020; Lai et al., 2021). Recent studies emphasise appropriate guidance, reflection, teacher support and inclusive learning environments (Gericke et al., 2022; Orosz et al., 2023; Denton & Kulesza, 2024; Mekonnen, 2025).

4.1 Research Gap

After study the review of related literature and also literature broadly focus on inquiry based science teaching rather than examination orientation teaching method. IBLI is a laboratory approach in which students understanding scientific process skills, laboratory competencies and scientific reasoning. Furthermore, the role of teacher preparation and the practical challenges involved in implementing inquiry oriented laboratory instruction require further investigation, particularly in the context of secondary Chemistry education. The present study therefore seeks to contribute to this area by examining IBLI as an innovative approach for strengthening the integration of theoretical Chemistry knowledge with practical laboratory experiences.

5 RESEARCH METHODOLOGY

The present study adopts a qualitative, literature based conceptual research methodology to examine Inquiry Based Laboratory Instructions (IBLI) as an innovative approach to the teaching of Chemistry. The study does not involve primary data collection or experimental intervention; rather, it systematically examines and synthesizes relevant theoretical perspectives, empirical studies and scholarly literature related to inquiry based learning, laboratory instruction, Chemistry education, scientific inquiry and innovative pedagogical practices. Such an approach is appropriate for developing theoretical and conceptual understanding and for identifying relationships and gaps within an existing body of research.

Objectives of the Study

- To conceptualize IBLI as an innovative approach to Chemistry teaching.
- To examine major components and theoretical foundations of IBLI.
- To analyze educational benefits of IBLI for Chemistry learning.
- To examine contextual factors and challenges influencing IBLI implementation.
- To integrating IBLI into Chemistry teaching and teacher education.

5.1 Significance of the Study

This study is important because it conceptualizes inquiry based laboratory instructions (IBLI) as a new approach to teaching chemistry that can strengthen the integration of theoretical knowledge with practical laboratory experiences. As an experimental discipline, chemistry requires learners to engage with phenomena through observation, questioning, investigation, experimentation, evidence analysis and scientific explanation. IBLI provides a structured pedagogical framework for incorporating these processes into laboratory learning, moving beyond the typically predetermined and procedural laboratory activities. This study is particularly important for chemistry learners because IBLI has the potential to promote conceptual understanding, scientific reasoning, scientific process skills, laboratory competencies, critical thinking, problem solving, curiosity and active engagement. It is promote meaningful chemistry laboratory learning with the help of students connect theoretical concepts with practical observations and experimental evidence. IBLI also supports teachers in designing learner centered activities, guiding inquiry, managing laboratory work and assessing scientific competencies. For teacher education, IBLI can strengthen prospective teachers' inquiry, scaffolding, laboratory management, assessment, safety and reflective teaching skills, while highlighting the need for institutional support. Identifying these needs can help create supportive conditions for meaningful inquiry based laboratory learning. Finally, this study contributes to chemistry education research by highlighting the need to examine IBLI as an integrated pedagogical framework that addresses conceptual understanding, scientific process skills, laboratory competence and scientific reasoning. As a conceptual study, it provides a foundation for future empirical research on the impact and implementation of IBLI in different educational contexts. Overall, the significance of this study lies in its ability to transform the chemistry laboratory from a mostly procedural setting to an environment that active investigation, evidence based reasoning, conceptual understanding, practical competence and scientific inquiry.

5.2 Need for Innovative Approaches in Chemistry Teaching

Traditional chemistry education often emphasis on content coverage, formulas, chemical equations, definitions and exam preparation. While these are essential for developing basic knowledge, an over-reliance on memorization and teacher centered learning can limit learners' opportunities to develop higher order cognitive, scientific and practical abilities. Effective chemistry learning requires students to not only acquire knowledge but also understand and apply concepts, investigate phenomena, interpret evidence and construct scientifically sound explanations. Thus, chemistry education needs to address multiple aspects, including conceptual understanding, scientific reasoning, laboratory skills, observation and measurement, problem solving, understanding evidence, scientific communication and applying knowledge to unfamiliar situations. Laboratory studies have great potential to connect theoretical concepts with practical experience. However, when laboratory activities are limited to predetermined procedures in which students simply follow instructions to obtain expected results, opportunities for questioning, independent thinking, experimentation and scientific reasoning may be limited. Therefore, a major concern in chemistry education is the gap between theoretical knowledge and practical experience. Students may memorize chemical equations, definitions and formulas but they fail to develop a deeper understanding of the phenomena and processes underlying them. Lab experiences that involve questioning, investigation, interpretation and explanation can provide richer learning opportunities than procedure oriented activities based primarily on compliance. The growing emphasis on learner centered, competency based, experiential and activity oriented education further highlights the need for new approaches to chemistry teaching. Today's science education focuses not only on what learners know but also on what they can do with their knowledge. Chemistry instruction should therefore provide opportunities for students to formulate questions, make predictions, plan investigations, collect and analyze evidence, draw conclusions and communicate scientific explanations. Inquiry Based Laboratory Instructions (IBLI) provides a structured alternative to highly procedural laboratory teaching. It places learners at the centre of the investigative process through interconnected activities such as questioning, prediction, experimental planning, observation, data analysis, explanation and reflection. It integrates experimentation, reasoning, problem solving, scientific skills, curiosity and engagement. Innovative approaches also have important implications for chemistry teacher education. Prospective teachers need opportunities to experience and practice pedagogical approaches that enable them to design and facilitate learner centered laboratory experiences. Exposure to IBLI can support the development of competencies in inquiry design, scientific questioning, laboratory management, instructional scaffolding, assessment and reflective practice. Therefore, the need for innovation in chemistry teaching arises from the necessity to move beyond passive knowledge acquisition and procedural laboratory work towards active investigation, conceptual understanding, practical competence,

scientific reasoning, and meaningful application of knowledge. In this context, IBLI offers a systematic framework for transforming the chemistry laboratory into an environment that promotes scientific inquiry, experiential learning and active knowledge construction. The present study consequently examines IBLI as an innovative pedagogical approach for strengthening the integration of theoretical chemistry concepts with practical laboratory experiences and enhancing learners' conceptual understanding, scientific process skills, laboratory competencies, and scientific reasoning.

6 IBLI IN CHEMISTRY TEACHING: ILLUSTRATIVE EXAMPLES

Inquiry Based Laboratory Instructions (IBLI) can be applied to diverse chemistry topics by transforming conventional practical activities into structured opportunities for investigation, experimentation, analysis and evidence based explanation. The following examples demonstrate how IBLI can be implemented with topic specific learning objectives.

6.1 Example 1: Separation of Mixtures

The teacher presents the problem: "How can a mixture containing iron filings, sand and common salt be separated into its individual components?"

Students examine the properties of the components and identify appropriate separation techniques, such as magnetic separation, dissolution, filtration and evaporation. They then conduct the investigation, compare the effectiveness of the methods, and explain the scientific principles involved.

Learning Objectives: Students will be able to:

- Identify the physical properties that enable different components of a mixture to be separated.
- Select and apply appropriate separation techniques.
- Explain the scientific principles underlying the selected methods.

6.2 Example 2: Factors Affecting the Rate of a Chemical Reaction

The teacher introduces the question: "What factors influence the rate at which a chemical reaction occurs?"

Students investigate a selected factor, such as temperature, concentration, surface area, or the presence of a catalyst. They compare experimental results and interpret the relationship between the selected variable and reaction rate.

Learning Objectives: Students will be able to:

- Identify variables that influence the rate of a chemical reaction.
- Design an investigation while controlling relevant variables.
- Interpret experimental evidence to explain changes in reaction rate.

6.3 Example 3: Acids, Bases, and Natural Indicators

The inquiry begins with the question: "Can substances obtained from natural sources be used to identify acidic and basic materials?"

Students investigate suitable natural indicators, such as red cabbage or turmeric, and test them with selected substances. They observe colour changes and classify the substances according to their acidic or basic properties.

Learning Objectives: Students will be able to:

- Identify suitable natural substances that can function as acid-base indicators.
- Use observable colour changes to distinguish between acidic and basic substances.
- Relate indicator responses to the chemical properties of acids and bases.

6.4 Example 4: Factors Affecting Solubility

The teacher poses the problem: "How does temperature affect the amount of a solid that dissolves in water?"

Students predict the effect of temperature; conduct an investigation using a suitable soluble substance, and compare observations or measurements obtained at different temperatures. They use the results to explain the observed relationship.

Learning Objectives: Students will be able to:

- Explain the concept of solubility in relation to dissolution.
- Investigate the relationship between temperature and the solubility of a selected substance.
- Interpret experimental results to identify patterns in solubility.

6.5 Example 5: Electrolysis of Water

The teacher introduces the question: “Can water be separated into simpler substances through a chemical process?”

Under appropriate supervision and safety conditions, students observe the electrolysis of water, compare the gases produced, and relate their observations to the composition of water. They then construct an evidence-based explanation of the process.

Learning Objectives: Students will be able to:

- Explain electrolysis as a process of chemical decomposition.
- Identify experimental evidence indicating the formation of different gases.
- Relate the observed products to the composition of water.

7 EDUCATIONAL BENEFITS OF INQUIRY BASED LABORATORY INSTRUCTIONS (IBLI) IN CHEMISTRY TEACHING

Inquiry Based Laboratory Instructions (IBLI) offers several educational benefits by transforming chemistry learning from passive knowledge acquisition into active scientific investigation. It enables students to connect theoretical concepts with practical experiences through questioning, experimentation, observation, data analysis and evidence based. IBLI promotes conceptual understanding, scientific reasoning, critical thinking, problem solving, creativity and scientific process skills. It also enhances students' curiosity, greater learner engagement, confidence and active participation in laboratory activities. By encouraging learners to investigate real life chemical phenomena, IBLI supports meaningful and experiential learning. Furthermore, it develops laboratory competencies, communication skills, positive attitudes towards chemistry, collaborative learning and the ability to apply scientific knowledge to unfamiliar situations, thereby strengthening overall chemistry learning.

7.1 Implications for Chemistry Teacher Education

IBLI has particular significance for prospective chemistry teachers. Teacher education programmes should not only teach future teachers about inquiry based learning but also provide opportunities for them to experience inquiry as learners. Future teacher may be trained to:

- Teacher can be design IBLI related activities.
- Convert chemistry related question by IBLI.
- Develop appropriate scaffolding
- Facilitate student discussion
- Create IBLI related environment.
- To increase practical competencies.
- Maintain laboratory safety
- Reflect on their own teaching practices.

8 DISCUSSION

The role of Inquiry-Based Laboratory Instruction (IBLI) extends beyond the traditional purpose of the chemistry laboratory. Instead of limiting practical work to following prescribed procedures and obtaining expected results, IBLI encourages students to use the laboratory as a space for exploring questions, investigating chemical phenomena, examining evidence, and developing their own explanations. In this way, laboratory learning becomes more closely connected with active learning, scientific practices, experiential learning, and the development of practical competencies. IBLI can also help reduce the gap between theoretical concepts discussed in the classroom and their application during practical activities. However, meaningful implementation of IBLI requires careful planning and appropriate support. Merely replacing a conventional laboratory manual with an open-ended activity may not provide students with a productive inquiry experience. Learners require suitable resources, clearly defined learning objectives, appropriate safety instructions, and assessment procedures. The teacher therefore has an important role in guiding the

inquiry process. Effective implementation requires teachers to judge when students need explicit guidance and when they can independently explore a problem or conduct an investigation.

9 CONCLUSION

Inquiry based laboratory instructions (IBLI) provide an approach to enhancing teaching and learning of chemistry. Inquiry Based Laboratory Instructions (IBLI) is a learner centered approach which offers an alternative pedagogical approach by transforming the laboratory from a place of following prescribed procedures to an environment of questioning, investigation, experimentation; evidence based reasoning and scientific communication. Inquiry based laboratory instructions gives student's greater opportunities to investigate, ask problems, examine evidence and relate practical aspect to theoretical aspects. These types of experiences will support the development of conceptual understanding, critical thinking, problem solving ability, laboratory competencies, collaboration and scientific reasoning. IBLI concept is supported by many educational perspectives, sum up by constructivism, experiential learning, discovery learning and scientific inquiry. The present study adopts a qualitative literature based conceptual research methodology to examine Inquiry Based Laboratory Instructions (IBLI) as an innovative approach to the teaching of Chemistry. Inquiry Based Laboratory Instructions grounded constructivist learning theory, experiential learning theory, discovery learning theory and scientific inquiry, it can designed inquiry based laboratory methods which promote active engagement, conceptual understanding, scientific process skills, problem-solving skill, collaboration and positive attitude towards chemistry. This study also explain need for innovative approaches in chemistry teaching with some illustrative examples such as separation of mixtures, factors affecting the rate of a chemical reaction; acids, bases and natural indicators, factors affecting solubility and electrolysis of water. IBLI has particular significance for prospective chemistry teachers. Teacher education programmes should not only teach future teachers about inquiry based learning but also provide opportunities for them to experience inquiry as learners.

Scope for Future Research

The scope of future research on Inquiry Based Laboratory Instructions (IBLI) as an Innovative Approach to the Teaching of Chemistry may focus on:

- The effect of IBLI on chemistry achievement
- Examine the influence on conceptual understanding
- To evaluate the effect of IBLI on scientific reasoning and problem solving
- Developing the learner approach of laboratory teaching.
- Students motivation and attitudes towards chemistry

Limitations of the Study

Present study has some limitations that should be considered after interpreting findings. This study do not empirically observed, there are no involvement of primary data and this study based only some literature of educational theories.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

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