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Research Article

Effect of Guided Inquiry-Based Laboratories on Improving Students' Performance in Chemistry Education

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Abstract
This study undertook an investigation of the pedagogical efficacy of guided inquiry-based laboratory activities on improving students' performance in chemistry education across four secondary schools in Rwanda. The investigation was necessitated by a persistent decline in learners' achievement in Organic Chemistry, unfavorable learner attitudes, minimal hands-on engagement, and entrenched reliance on experimental verification rather than inquiry-driven exploration during practical sessions. The study further sought the teachers' perceptions of guided inquiry-based laboratory activities, identified the challenges constraining their implementation, and determined their influence on students' academic outcomes. This study used a mixed-methods research design with stratified and purposive sampling to identify four chemistry teachers and 447 students, with an 82-sample size from senior five students studying chemistry at the advanced level. The study employed a one-group, pretest-posttest design with experimental and control groups. Data were gathered utilizing a practical lesson observation schedule, a teacher-structured interview, and a student questionnaire. The findings revealed that inadequate laboratory facilities and insufficient teacher professional development perpetuated the dominance of demonstration-based instructional strategies. Moreover, the examination-oriented national curriculum framework implicitly prioritized theoretical mastery and procedural replication over inquiry-oriented laboratory engagement. Notwithstanding these constraints, guided inquiry-based laboratory activities were found to substantially enhance students' conceptual understanding, cognitive engagement, and attitudinal disposition toward Organic Chemistry. The control group's mean score improved from 23.5 to 28.7; the experimental group demonstrated a more pronounced gain, increasing from 24.08 to 33.5, accompanied by reduced posttest score dispersion, indicative of more consistent learning progress. The study concludes that guided inquiry-based laboratory activities possess considerable pedagogical potential in improving Organic Chemistry learning outcomes. It therefore advocates for targeted teacher training initiatives and enhanced resource allocation to facilitate a paradigm shift from demonstration-oriented practices toward inquiry-centered laboratory instruction.

Keywords: Guided Inquiry-Based, Laboratory Activities, Organic Chemistry

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1. INTRODUCTION

Locally, in Rwanda, the education system has undergone substantial transformation since the introduction of the Competence-Based Curriculum (CBC) in 2015, which emphasizes learner-centered methods, including inquiry and practical work (Drocelle, 2020; MINEDUC, 2018). The Rwanda Basic Education Board (REB) and the Ministry of Education have encouraged schools to incorporate laboratory-based inquiry in science instruction (Nsengimana, 2021). Yet, the practical application of these methods, particularly in the domain of organic chemistry and ethanol-derived functional groups, remains limited by factors such as a lack of laboratory infrastructure, insufficient teacher training, and inadequate materials

(Manishimwe et al., 2023; Ningsih, 2024). Organic Chemistry is often perceived as a difficult subject by senior five students due to its abstract content and the high-level cognitive skills it demands (Seery et al., 2024). Traditional teacher-centered instructional strategies, which emphasize rote learning, have resulted in limited student engagement, poor conceptual understanding, and underperformance in Organic Chemistry (Anim-Eduful & Adu-Gyamfi, 2022). Many students struggle to translate theoretical knowledge into practical applications, further weakening their grasp of the subject (Renzaho & Kampire, 2022)

Guided inquiry-based laboratory (GIBL) activities have been shown to support conceptual understanding, foster analytical thinking, and improve academic performance (Gao & Lloyd, 2020; Kaneza et al., 2024; Ojo et al., 2025). Their implementation in secondary schools remains inconsistent. However, their alignment with curriculum expectations remains a challenge (Mukandayisenga et al., 2021), particularly in schools with limited resources and poorly equipped laboratories (Guo et al., 2020; Nkurunziza et al., 2023).

Despite these constraints, anecdotal and preliminary research indicate that when inquiry-based laboratory activities are effectively implemented, Rwandan students exhibit enhanced conceptual understanding, increased motivation, and improved performance in organic chemistry (Mbonimpaye et al., 2021). The persistent use of verification-based experiments restricts students' development of practical skills and limits their scientific curiosity. Additionally, issues such as inadequate chemical supplies and poor waste management (Destino et al., 2021; REMA, 2023). A general lack of training in inquiry-based instruction further hinders effective teaching and learning in Organic Chemistry (Ndahimana & Nkundabakura, 2023). The students exposed to the crafted models showed an improvement in their understanding of atomic structure and achieved higher scores in chemistry assessments compared to their peers in the control group. Additionally, both students and teachers reported increased interest and engagement in chemistry lessons when using these visual aids (Ruterana et. al., 2024; Twahirwa et al., 2021).

1.1. Literature Review

1.1.1. Literature Review

Guided Inquiry-Based Laboratory Activities (GIBLA) have emerged as a transformative approach in science education, particularly in the teaching of organic chemistry. One of the most significant benefits reported is the enhancement of students' scientific reasoning and autonomy (Dufitumukiza, 2021). Teachers acknowledge that GIBLA nurtures independence, allowing learners to shift from passive recipients of information to active sleuths (Ndihokubwayo & Habiyaremye, 2018). This transformation is particularly meaningful in organic chemistry, where students are often required to apply theoretical knowledge to novel and complex experimental scenarios (Chen et al., 2024). Through guided inquiry, students also develop essential 21st-century competencies such as communication, collaboration, and presentation skills, all of which are integral to scientific practice (Irwanto et al., 2019). Despite its pedagogical promise, GIBLA presents notable implementation challenges for teachers (Urdanivia et al., 2023). Unlike traditional laboratory exercises that follow fixed steps, guided inquiry demands the design of open-ended experiments, anticipation of diverse student responses, and flexibility in supporting multiple investigative pathways (Shambare & Simuja, 2024).

Another critical barrier is the insufficient professional training available to teachers (Blumer & Beck, 2018). Many teachers feel unprepared to use inquiry-based strategies effectively, often due to a lack of exposure during teacher education and minimal ongoing professional development (Aidoo, 2016). Without proper support, teachers struggle to balance the open-ended nature of inquiry with the need to guide students toward scientifically accurate understandings (Situmorang et al., 2020). Consequently, some teachers revert to more traditional, didactic teaching methods, diminishing the potential impact of GIBLA (Aliyu et al., 2023; Burrows et al., 2017).

Furthermore, addressing student misconceptions presents a distinct challenge in inquiry-based learning environments (Wakumire et al., 2022). In the context of GIBLA, assessing student learning is equally complex (Deng et al., 2023). Conventional evaluation methods, such as written examinations, often fall short in measuring essential inquiry-driven skills like problem-solving, experimental design, and scientific communication (Naiker & Wakeling, 2015). Consequently, teachers face difficulties in designing assessment tools that accurately and reliably capture both the procedural and conceptual aspects of students' learning within guided inquiry frameworks (Brederode et al., 2020; Kaime & Sifuna, 2007)

The pivotal role of critical thinking and reflective practices in laboratory education emphasizes their contribution to deepening students' conceptual understanding and scientific reasoning. Research demonstrates that integrating guided-inquiry methods with structured reflection, such as journaling, significantly enhances students' metacognitive skills and critical analysis of experimental outcomes (Adauyah & Aznam, 2024; Montgomery et al., 2022).

Innovative responses to infrastructural limitations, including "Lab Hackathons" in African contexts, illustrate the potential of grassroots technological solutions to improve access to essential laboratory equipment and support inquiry-based learning despite resource constraints (Adauyah & Aznam, 2024). In Rwandan secondary chemistry classrooms, active learning strategies dominate instructional time; however, assessment practices lag, highlighting a need for alignment between inquiry engagement and evaluative methods (Byusa et al., 2021).

The use of technology to facilitate inquiry is gaining traction, as younger teachers demonstrate higher digital pedagogical competencies, and interactive tools such as PhET simulations have been shown to significantly improve student understanding of complex chemical concepts (Hanson, 2017; Wakumire et al., 2022). In American institutions, guided-inquiry interventions using conceptual checkpoints enhance cognitive engagement and reflection, suggesting that scaffolding supports can deepen laboratory learning experiences even without direct exam performance data (Baur & Emden, 2021).

1.1.2. Theoretical framework

This study uses Constructivist Learning Theory to examine the effectiveness of guided inquiry-based laboratory activities in Organic Chemistry. Constructivism emphasizes active engagement in learning, focusing on students' cognitive development, social interaction, and scaffolding. This theory is influenced by Jean Piaget, Lev Vygotsky, and Jerome Bruner, who emphasized student-centered learning, developmental readiness, and social interaction (Chand, 2024). In this context, guided inquiry-based laboratory activities allow students to design experiments, observe, analyze data, and draw conclusions. The teacher acts as a facilitator, providing structure and allowing students to explore, hypothesize, and construct knowledge through dialogue and collaborative experimentation. Constructivist classrooms are characterized by reflexive, collaborative, inquiry-based, and dynamic learning experiences (Piaget, 1979). By integrating constructivist principles with inquiry-based and experiential learning strategies, teachers create laboratory environments that foster deeper student engagement, critical thinking, and problem-solving skills, and they ensure student safety and contextual understanding (Shultz & Li, 2023).

2. METHODS

2.1. Research Design

The research approach outlines the process of carrying out a study, describing its general goal and data gathering criteria. A research design, as defined by Gorard and Taylor (2019), establishes a framework for data collection that balances between the study's relevance and its objectives. Accordingly, this study adopted an explanatory sequence design. It consists of a two-phase structure (Mugabo & Nsengimana, 2020). The first phase involves the collection and analysis of quantitative and qualitative data using statistical methods. The qualitative phase, incorporating interviews and focus groups, provided deeper insights and contributed to the improvement of teaching methods (Mwenda & Ndayambaje, 2021).

The quasi-experimental study followed a non-randomized pre-test and post-test control design. Aiming to study the mixed research methodology on the effect of guided inquiry-based laboratory activities in enhancing the performance of senior five students in organic chemistry at the secondary school level.

2.1.1. Experimental

2.1.1.1. Dehydration of Ethanol in the Synthesis of Diethyl Ether

This chemical reaction involves the removal of a water molecule (H_2O) from two ethanol (C_2H_5OH) molecules to form diethyl ether ($C_2H_5OC_2H_5$). In the laboratory, diethyl ether is prepared from ethanol through a dehydration reaction, in which ethanol reacts with concentrated sulfuric acid (H_2SO_4) to produce diethyl ether and water. The procedure begins by placing 10 mL of ethanol in a round-bottom flask and adding 5–10 mL of concentrated sulfuric acid. The mixture is then heated gently under reflux at 140–150°C to prevent the volatile ether from escaping. Sulfuric acid acts as a dehydrating agent, removing water from ethanol and facilitating the formation of diethyl ether.

Reaction:

$$2\ C_2H_5OH \xrightarrow[140^0c]{H_2SO_4} C_2H_5OC_2H_5 + H_2O$$

2.1.1.2. Oxidation of Ethanol in the Synthesis of Carboxylic Acid

The procedure begins by measuring 50 mL of ethanol and transferring it into a 500 mL round-bottom flask. Subsequently, 85 mL of acidified potassium permanganate solution is gradually added. After assembling the distillation apparatus, the mixture is heated under reflux conditions to initiate the oxidation process. In the first stage, ethanol is oxidized to acetaldehyde (CH_3CHO), which is then further oxidized to acetic acid (CH_3COOH)

Reaction:

$$C_2H_5OH \xrightarrow[oxidation]{[O]} CH_3CHO \xrightarrow[oxidation]{[O]} CH_3COOH$$

2.1.1.3. Oxidation of Ethanol in the Synthesis of Ethanal

Ethanal, also known as acetaldehyde, is prepared by controlled oxidation of ethanol using sodium dichromate in the presence of concentrated sulfuric acid. The process involves dissolving sodium dichromate in distilled water, adding 40 mL of ethanol, and stirring thoroughly. In a round-bottom flask with a condenser and set in an ice-water bath, slowly run the alcohol/dichromate solution into cold concentrated sulfuric acid.

Reaction :

$$C_2H_5OH \xrightarrow[oxidation]{[O]} CH_3CHO$$

2.1.1.4. Synthesis of Acetamide from Ethanol

The process of producing acetamide from ethanol involves a two-step process: oxidation of ethanol to acetic acid and conversion of acetic acid to acetamide. The oxidation process involves adding ethanol slowly to an oxidizing solution, stirring it, and heating it gently to 60-70°C. The ethanol is then oxidized to acetic acid (CH_3COOH), which is then collected and distilled. The conversion of acetic acid to acetamide involves combining acetic acid with ammonia solution (NH_3(aq) (Nguyen & Tran, 2024). The reaction involves heating the mixture gently to drive the reaction to completion. The oxidation of ethanol to acetic acid is an exothermic reaction, so handle the reagents with care and ensure that ammonia or ammonium salts are added gradually to avoid excessive heat or pressure buildup (Ncutinamagara et al., 2023).

2.2. Research Participants

The study involved a target population of 451 participants, including 447 senior five Chemistry students and 4 chemistry teachers from four secondary schools in Rwanda. Using Yamane's formula with a 90% confidence level and a 10% margin of error, a representative sample of 82 participants was selected (see Table 1). This comprised sampled students from each school and all four Chemistry teachers. The sampling approach ensured adequate representation and supported the reliability of the study findings.

Table 1. Distribution of Target Population, Calculated Sample Size, and Gender Composition of Teachers and Students, Including Frequencies and Percentages

Target Population	Sample size	Gender (Teachers and Students)		Teachers		Percentage	
		Male	Female	Male	Female	Male	Female
451	$\frac{451}{1+451X(0.1)^2}=82$	33	49	4	0	40.2	59.8

2.3. Research Instruments

The study utilized an intricate mixed-methods design to interrogate the pedagogical efficacy of guided inquiry-based laboratory activities on senior five students' Organic Chemistry performance. Quantitative pre- and post-test assessments, aligned with the Rwanda Chemistry curriculum, measured cognitive gains, attitudes, and interest, analyzed via descriptive statistics and inferential t-tests. Complementarily, teacher interviews, student questionnaires, and observational checklists captured qualitative insights into instructional implementation, engagement, and experiential learning (Kwitonda et al., 2021). Targeted teacher professional development augmented pedagogical delivery. Triangulation of these multifaceted data sources facilitated a rigorous, nuanced appraisal of both academic outcomes and attitudinal transformations engendered by inquiry-based laboratory interventions (Haradhan, 2020).

3. RESULTS

3.1. Effect of Guided Inquiry-Based Laboratory Approach on Students' Academic Enhancement in Organic Chemistry

Senior Five (S5) Chemistry students study organic chemistry, covering topics like Alcohols, Ethers, Aldehydes, Carboxylic Acids, and Amides (REB, 2020).

Table 2. Synthesized Ethanol-based Product vs Commercial Chemicals

SN	Type of Reaction	Synthesized Ethanol-Based Product	Commercial Comparison
1	Oxidation to acetic acid	$CH_3CH_2OH + H_2SO_4 + [O] \rightarrow CH_3COOH$	Ethanol is oxidized to acetaldehyde Acetaldehyde is readily oxidized to acetic acid
2	Oxidation to acetaldehyde	$CH_3CH_2OH + H_2SO_4 + [O] \rightarrow CH_3CHO + H_2O$	Alcohol is oxidized to acetaldehyde under controlled conditions to avoid subsequent oxidation to acid
3	Amide formation	$CH_3COOH + NH_3 \rightarrow CH_3CONH_2 + H_2O$	Commercially used for higher efficiency
4	Dehydration to Ether	$2\ CH_3CH_2OH \rightarrow CH_3CH_2OCH_2CH_3 + H_2O$ (with H_2SO_4, 140^0C)	Pure ethanol yields a higher diethyl ether yield

Table 2 shows the synthesized ethanol-based products, which are a safer alternative, commercial chemicals remain dominant in many sectors due to their efficiency. The choice between the two often depends on the specific application and regulatory requirements.

3.2. Characterization of Synthesized Ethanol-Based Product

Ethanol-based products have become increasingly prominent in various industries due to their effectiveness, safety, and eco-friendly nature. Commonly used in disinfectants, personal care items, pharmaceuticals, and biofuels, ethanol serves as a key active ingredient owing to its solvent properties and antimicrobial activity. As demand for sustainable and biodegradable alternatives to synthetic chemicals grows, ethanol-based formulations are gaining preference. Characterizing these products is essential to evaluate their quality, functionality, and suitability for specific applications.

Table 3. Chemical and Physical Characterization of Ethanol-Based Product

Compound	Chemical Test	Positive Observation	Functional Group Confirmed	Interpretation
Acetaldehyde	Fehling's Test (deep blue)	Brick-red precipitate	Aldehyde	The formation of a brick-red precipitate indicates that the compound contains an aldehyde group capable of reducing Cu^{2+} to (copper(I) oxide). This confirms acetaldehyde's presence as a reactive aldehyde intermediate formed by partial oxidation of ethanol.
Acetic Acid	$NaHCO_3$, Test	Effervescence (CO_2 gas)	Carboxylic acid (–COOH)	Effervescence shows the release of carbon dioxide gas, confirming the presence of a carboxylic acid functional group. Acetic acid reacts with bicarbonate to release CO_2, distinguishing it from other ethanol oxidation products.
Acetamide	Hydrolysis	Ammonia smell	Amide (–$CONH_2$)	On hydrolysis under acidic or basic conditions, the smell of ammonia confirms the presence of an amide group. This test verifies that acetamide, formed from acetic acid and ammonia, is present.
Diethyl Ether	Smell/Solubility	H_2SO_4, 140°C	Ether (–O–)	The characteristic ether smell. This test is qualitative and relies on sensory observation of the ether's distinct odor, confirming successful dehydration of ethanol to ether.

3.3. Homogeneity of Study Groups After the Intervention of Guided Inquiry-Based Laboratory Activities in Chemistry

Homogeneity encompasses consistent academic success, equivalent conceptual knowledge, and the same problem-solving techniques. Active engagement increases deeper learning, reduces performance differences, and ensures consistent post-test results.

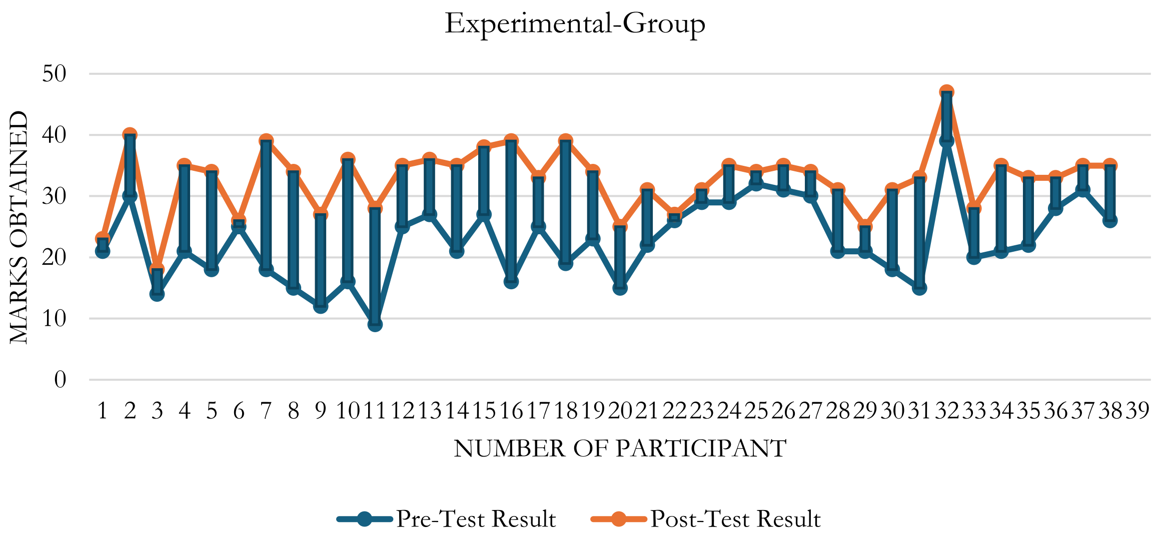

Figure 1. Experimental Group Results in Pre-test and Post-Test

Figure 1 shows an effective intervention by teachers; they assisted them in acquiring new teaching techniques. This was reflected in post-test scores, which indicated that the intervention was successful in improving the group's performance. The experimental group has learnt new abilities throughout the research period, which resulted in increased post-test performance.

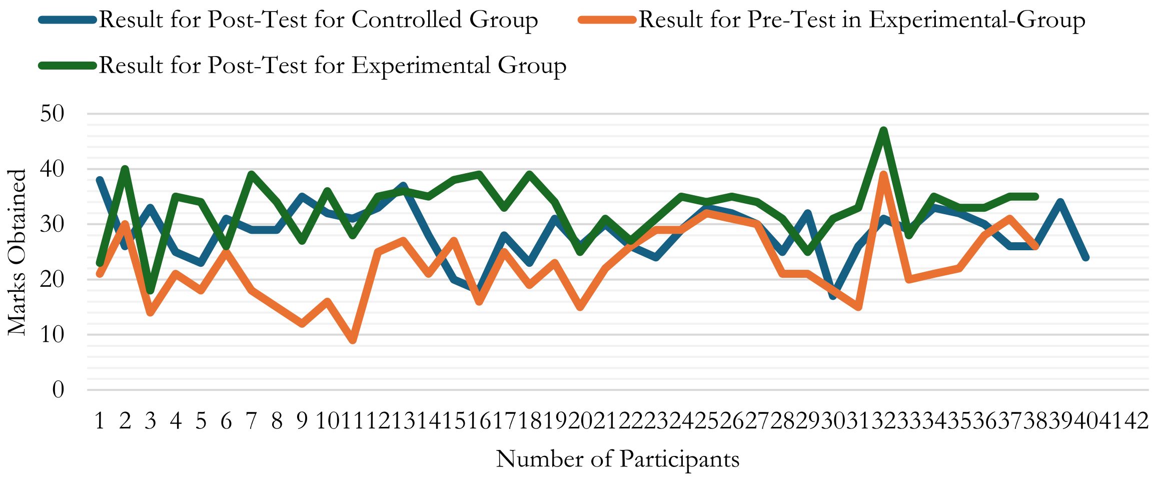

Figure 2. Result of Participant

Figure 2 shows that the guided inquiry-based laboratory activities were an efficient way to teach organic chemistry to Senior Five students. These hands-on exercises promoted active learning by allowing students to investigate topics and solve issues individually. These exercises piqued students' inherent curiosity, boosting their interest in the subject. They also frequently included group activities.

3.4. Analysis of Students' Performance between the Control Group and Experimental Group

The study employed three quantitative instruments: an accomplishment test, an attitude scale, and an interest scale. Both pre- and post-tests were applied. The accomplishment test consisted of 20 multiple-choice items with dichotomous scoring, with a maximum score of 50 and good reliability (Cronbach's α = 0.82). A 20-item five-point Likert scale with reverse scoring for negatively phrased items was used to measure attitudes, yielding reliable results ($\alpha = 0.86$). Students' interest was measured using a 15-item, five-point Likert scale; mean scores showed acceptable reliability ($\alpha = 0.84$) and overall interest. The data analysis included paired-samples t-tests with $\alpha = 0.05$ and descriptive statistics.

Table 4. Descriptive Statistics of Pre-Test Results For The Experimental and Control Groups

		Result in Pre-Test Experimental Group	**Result in Pre-Test Controlled Group**
N	Valid	38	44
	Missing	0	0
Mean		24.1	23.5
Median		24.5	20.5
Mode		21.00	20.00
Std. Deviation		7.1	5.9
Skewness		.014	.261

According to Table 4, a uniform data distribution is associated with greater homogeneity, as seen by a lower standard deviation and less dispersion, while skewness denotes distributional asymmetry. By controlling for baseline ability variations, the study was able to successfully isolate treatment effects and identify differences across performance levels, which is consistent with frameworks for guided inquiry-based laboratory activities. Analysis of the four schools' ratings revealed comparable baseline performance with no appreciable pre-intervention differences. The non-significant *p*-values ($p > 0.05$), which suggested that observed correlations were more likely to be the result of random fluctuation than significant effects.

3.5. Interview Conducted for Teachers from Four Selected Rwandan Secondary Schools

This research included interviews with teachers from four selected secondary schools in Rwanda. These interviews aimed to collect detailed insights into teachers' experiences, views, and challenges related to Guided inquiry-based laboratory activities. Teachers in secondary schools play a crucial role in influencing educational quality, and their perspectives provide valuable insights into the practical realities of the education system. The four schools were intentionally selected to reflect a variety of contexts, encompassing urban and rural areas, different school sizes, and a range of academic achievement levels. The interviews were semi-structured, allowing participants to express their opinions openly while ensuring that key topics relevant to the study were addressed.

Question 1. *In contrast to demonstrative laboratory experiments, how do chemistry teachers view the necessity of specialized training while conducting guided inquiry-based laboratory activities?*

Guided inquiry-based laboratory activities (GIBLA) engage students in active problem-solving, critical thinking, and hands-on investigation, in contrast to traditional demonstrative experiments where the teacher directs and students observe. This student-centred approach, aligned with Rwanda's Competence-Based Curriculum, positions teachers as facilitators who guide, question, and support learners, fostering self-directed learning and a deeper understanding of organic chemistry concepts such as reaction mechanisms, synthesis, and structural analysis. Teachers recognize GIBLA's benefits for enhancing critical thinking, collaboration, and real-world application, though challenges such as limited resources, time constraints, and larger class sizes may hinder implementation. Overall, GIBLA is viewed as highly effective in improving student engagement, problem-solving skills, and academic outcomes compared to demonstrative methods.

Question 2: *What are the challenges faced in terms of resources, time, and facilities when implementing guided inquiry-based laboratory activities versus demonstrative laboratory experiments*

In school, guided inquiry-based laboratory operations confront obstacles such as resource scarcity, time limits, and facility limitations. These activities need more resources, longer experiment durations, and enough lab space, which are sometimes in limited supply in secondary schools. These problems impede the implementation of these activities, which promote critical thinking and knowledge of organic chemistry ideas. Despite these obstacles, demonstrative laboratory studies are more efficient; yet, they frequently demand passive learning and limit student liberty. Teachers must modify their courses to incorporate inquiry-based paradigms.

Question 3: What are *the misconceptions that teachers faced when transitioning from demonstrative laboratory methods to guided inquiry-based approaches in organic chemistry*

Teachers were disconcerted that inquiry-based learning was unduly esoteric, especially in organic chemistry. They expressed that it was time-consuming and unhelpful when teaching complex topics. Transitioning to guided inquiry-based teaching placed teachers under pressure to respond to every student's question. They also believed that students worked alone or in groups without supervision. Guided inquiry-based laboratory activities were chaotic and difficult to manage, with students becoming abstracted or struggling to focus on important issues.

Question 4: *The pedagogical and practical challenges that teachers faced when conducting guided inquiry-based laboratory activities in organic chemistry, and how these challenges have an impact on student learning outcomes*

Teachers in a guided inquiry context served as facilitators, and they helped the students in the learning process. Students experienced bewilderment and worry as they adjusted to increasing autonomy and responsibility. In order to be effective, inquiry-based learning was planned carefully and was flexible in the classroom. The inadequate scaffolding, antiquated equipment, safety precautions, and specialized labs can all impede students' involvement, and safety measures were taken; there were enough classroom and well-equipped laboratory activities to overcome the challenge. Demonstrative laboratory activities were not comparable with inquiry-based learning, and there was insufficient laboratory material and chemicals. Teachers did not have enough skills to conduct laboratory activities.

4. DISCUSSION

The data elucidate a pronounced enhancement in students' conceptual apprehension of ethanol-based products subsequent to participation in guided inquiry-based laboratory activities (GIBLA), as juxtaposed with those exposed exclusively to demonstrative modalities. Notwithstanding that 52.42% of chemistry instructors articulated strong endorsement of inquiry pedagogy, actual implementation remained circumscribed, an incongruity attributable to systemic impediments such as deficient professional preparation, resource scarcity, temporal constraints, and variable student readiness, consistent with extant research on inquiry integration challenges (Akuma & Callaghan, 2019; Windschitl et al., 2018). Students immersed in GIBLA exhibited superior depth of understanding regarding ethanol synthesis pathways, mechanistic rationales, and applicative contexts, including biofuel viability relative to peers confined to replication-oriented demonstrations, whose conceptualizations remained predominantly procedural and descriptive.

Within the inquiry cohort, students engaged in hypothesis formulation, experimental design, and data interpretation, thereby mediating substantive links between theoretical constructs and empirical practice and corroborating constructivist assertions that active epistemic engagement fosters durable cognitive schemata (Irwanto et al., 2019). Conversely, demonstrative participants demonstrated limited integration of underlying principles, evidencing surface learning. Notably, initial disorientation among some learners toward the open-ended inquiry tasks underscores the necessity of calibrated scaffolding to optimize access and equitable attainment, aligning with Vygotsky's zone of proximal development (Vygotsky, 1978) and contemporary discourse on differentiated inquiry facilitation (Dufitumukiza, 2021). Furthermore, teachers who accessed targeted professional development manifested enhanced pedagogical agency and receptivity to inquiry enactment, suggesting that sustained institutional support is indispensable for meaningful pedagogical transformation.

5. CONCLUSION

Guided inquiry-based laboratory activities (GIBLA) position students as active agents in the learning process, fostering higher-order cognitive skills such as critical thinking, scientific reasoning, and evidence-based problem-solving. This approach promotes deeper conceptual understanding of complex organic chemistry phenomena, including reaction mechanisms and synthetic processes, while enhancing engagement, motivation, and confidence. Despite its pedagogical benefits, implementation is constrained by practical challenges such as limited instructional time, classroom management demands, insufficient resources, and assessment misalignment. Nonetheless, GIBLA provides equitable and collaborative learning opportunities, benefiting students across diverse ability levels, with prior knowledge influencing the degree of engagement and enjoyment.

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Research Ethics. All procedures in this study were conducted in strict accordance with applicable laws and institutional regulations.

Data Availability Statement. The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request. All data supporting the findings of this study are included within the manuscript and supplementary materials.

Conflicts of Interest. The authors declare no conflicts of interest, financial or non-financial, that could have influenced the outcomes or interpretation of this research.

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