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Learning Outcomes of the Inquiry-in-Action Model for Chemistry Experimentation

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Abstract

There is overwhelming evidence supporting the decline of science education in Liberia. In an effort to contribute to the solution, we conducted a study to examine the impact of inquiry-based experimentation and conventional demonstration on the conceptual understanding of solutions and solubility among grade eleven students. We also investigated the relationship between students' achievement scores in solution and solubility and their science inquiry process skills. Initially, a cluster random sample of eight schools was selected from a pool of 31 high schools based on their availability of space and materials for experimentation. The experimental and control groups were then subjected to six weeks of instruction using the inquiry-based and traditional experimentation demonstration teaching methods, respectively. The results were analyzed using the Mann-Whitney U and Wilcoxon Signed Rank tests. The inquiry-based experimentation approach was found to reduce students' anxiety and increase their confidence in chemistry experiments. While the inquiry-in-action model enhanced learners' conceptual understanding of theoretical aspects of solutions and solubility, it did not significantly improve their mastery of the mathematical components of the test. However, it did have a significant positive impact on students' science inquiry process skills. It is important to note that while the inquiry-in-action model positively influenced learners' attitudes, preferences, behavior, and anxiety levels in chemistry experiments, it also led to a general lack of motivation to learn chemistry through experimentation. Additionally, there was a positive correlation between students' attitudes toward teaching and learning chemistry through experiments and their science inquiry process skills. However, this correlation was stronger for attitudes from the demonstration of experiments than those from the inquiry-in-action model. This suggests that the traditional demonstration approach is not entirely ineffective, and a combination of both demonstration and inquiry-based experimentation approaches may maximize the benefits of science experiments.

Keywords: Demonstration; Experimentation; Inquiry-in-action; Science process skills; Solutions and solubility

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INTRODUCTION

There is widespread recognition that science and technology are crucial for economic growth and national development (Anastas & Zimmerman, 2018; Mehta & Kulshrestha, 2014; Oliveira et al., 2021; Vincent-Lancrin, 2021). Chemistry has been identified within the sciences as the cornerstone upon which science and technology are built, making it the central science (Brown et al., 2017). Adewumi and Monisola (2013) describe chemistry as the catalyst for sustainable growth. Based on these points, it is reasonable to emphasize efforts to strengthen teaching approaches in chemistry classes, particularly in secondary schools where the foundation is laid. This is necessary to ensure the attainment of core competencies necessary for advancing science and technology (Hauspie et al., 2023).

The use of the learning cycle in teaching has been identified as one of the methods for acquiring scientific competencies. This approach, which involves dividing classroom activities into sequential phases, aligns with inquiry-based teaching (Sesen & Tarhan, 2013). Various versions of the learning cycle exist in the research literature, one example being the 4-H inquiry-in-action model developed by Arnold et al. (Arnold et al., 2013). This teaching model, which informs the present study, focuses on developing young learners' interest in STEM disciplines. The inquiry-based teaching model encourages both hands-on and minds-on opportunities, as engaging learners in experimentation and practical activities enhances their understanding (Dass, 2015; Kiazai et al., 2020). Research across different cultures overwhelmingly supports the use of inquiry-based experimentation in enhancing conceptual understanding (Constantinou et al., 2018; Dinçol Özgür & Yılmaz, 2017; El Mawas & Muntean, 2018; Koksal & Berberoglu, 2014; Minner et al., 2010; Nicol, 2021; Riga et al., 2017; Van Uum et al., 2016). However, studies such as those conducted by Furtak et al. (2012) and Korkmaz (2012) showed no significant differences between students taught using inquiry-based methods and those taught using other means.

Regarding attitudes toward science, the findings of this study are in line with the results of previous research (George-Williams et al., 2018; Henige, 2011; Horsley & Moeed, 2018; Nedungadi et al., 2015), although a study by Montes et al. (2018) found some students to be apprehensive in their attitudes. Furthermore, previous research has demonstrated the enhancement of science inquiry process skills (Hardianti & Kuswanto, 2017; Ogan-Bekiroğlu & Arslan, 2014; Pulungan et al., 2021; Sahintepe et al., 2020). However, studies by Ogan-Bekiroglu and Arslan (2014), Bunterm et al. (2014), and Hardianti and Kuwanto (2017) did not observe significant differences in science process skills. Regardless of the scientific evidence supporting inquiry-based instruction, secondary school learners do not have sufficient opportunities to explore and reap the benefits of this approach (Chowdhury, 2014). Practicing teachers and researchers in various contexts agree that traditional cookbook laboratory methods dominate experimental instruction in secondary schools (Abraham & Collins, 2011; Cheung, 2009; Sesen & Tarhan, 2013; Ural, 2016). Stakeholders in science education recognize the need to advocate for evidence-based approaches to teaching science.

As science educators increasingly question conventional methods of science experimentation, global education leaders have acknowledged the need to revise science instruction in schools (Almetov et al., 2020; Prudnikov, 2020). Advocacy for inquiry-based experimentation has gained significant momentum recently (Sesen & Tarhan, 2013). For example, the United States developed the National Science Education Standards in 1996 as a response to unsatisfactory academic performance by high school students in important exams. These standards serve as the foundation for contemporary inquiry-based teaching techniques (Chatterjee et al., 2009; Visser-Wijnveen et al., 2016). Similarly, educational systems in China (Li et al., 2019), South Africa (Harlen, 2013), and other diverse cultures are transitioning from rigid, structured models of teaching science to ones that grant learners greater freedom to explore and discover knowledge.

Several studies investigating the effectiveness of innovative teaching methods in secondary schools have been conducted in West Africa (Omorogbe & Ewansiha, 2013), with positive outcomes. However, very few of these studies are situated in Liberia (Gberie & Mosley, 2016; Gbollie & Keamu, 2017; Hinneh & Nenty, 2016). Moreover, none of these studies specifically focused on the efficacy of a teaching approach in achieving better learning outcomes. The West African Examinations Council, responsible for administering the West African Senior Secondary Certificate Examination, has reported that students have consistently demonstrated inadequate knowledge in solutions and solubility in chemistry essay tests over the past five years. Based on this, the six-week instructional intervention in this study focused on solutions and solubility.

Despite the widespread acclaim for the inquiry-based method of instruction, critics argue that it can undermine learning due to cognitive overload and minimal guidance. Bolte and Diehl (2013) observed that high-achieving learners tend to dislike inquiry-based strategies, while Taber (2013) suggested that such approaches not only lead to cognitive overload but also consume valuable instructional time. Tan et al. (2014) further noted that many studies reporting positive outcomes of inquiry-based teaching lack statistical justification for generalizing their findings due to small sample sizes.

The Liberian Ministry of Education introduced a competency-based curriculum in secondary schools in 2018, emphasizing practical work in the sciences with appropriate teacher guidance. However, inadequate science laboratory facilities and a lack of teacher motivation hinder implementing this valuable practical experience. In the few schools where science experiments are visible, they are often conducted as demonstrations, with teachers alone performing the experiments while students passively observe (Chan et al., 2015; Kinyota, 2020). This lack of practical experience may partially contribute to the poor performance of candidates in chemistry and other subjects (Shwartz et al., 2021), as evidenced by below-average scores in the West African Senior Secondary Certificate Examination (WAEC, 2016, 2017).

Findings from the National Learning Assessment Policy Pilot (NLAPP) study revealed a chemistry pass rate of 14% in the 2020 West African Senior Secondary Certificate Examination. The report attributed this low pass rate to inadequate teacher preparation and inappropriate teaching methods (Nicol et al., 2022). In 2021, the results for chemistry in the West African Senior Secondary Certificate Examination showed slight improvement, with 0.47% of candidates earning a credit and 5.05% scoring in the "pass" range. These challenges and indicators highlight the need for an innovative approach to teaching and better teacher preparation. This study aims to investigate the use of an inquiry-based approach to teaching chemistry experimentation as a possible means of enhancing learners' academic performance in Bong County high schools in Liberia. The study addressed the following research questions:

1. How does inquiry experimentation impact students' conceptual understanding of solutions and solubility?
2. How do inquiry experimentation teaching methods affect students' attitudes toward learning?
3. How does inquiry experimentation influence students' science inquiry process skills?

4. What is the relationship between students' attitudes towards teaching and learning chemistry and their science inquiry process skills?

METHOD

Research Participant

The participants in this study consisted of grade eleven students from eight senior secondary schools in Bong County. Please refer to Table 1 for a detailed breakdown of the number of participants who completed each data collection instrument. These students were chosen because they were beneficiaries of a revised national curriculum that was implemented in 2018. This curriculum places a strong emphasis on developing competencies that are crucial for the holistic growth of the learners. Grade eleven was specifically selected for this study because the teachers expressed their willingness to implement the intervention. Additionally, the fact that these students were in mid-high school made them uniquely suitable for the study, as they possessed the necessary high school experience.

Table 1. Number of Respondents

Test	Number of pre-tested students		Number of post-tested students	
	Inquiry	**Demonstration**	**Inquiry**	**Demonstration**
SSAT	185	182	192	165
SIPSI	200	175	169	176
Total	385	182	361	165

The Non-equivalent control group variant of the quasi-experimental research design, as depicted in Table 2, was employed for this study. This design facilitates the allocation of subjects into intact groups, thereby creating experimental and control groups (Fraenkel et al., 2012). Opting to assign intact groups of students into experimental and control groups was deemed appropriate, as it minimized disruption to the academic programs of students who had already been organized into classes prior to the research team's involvement with the schools.

Table 2. The Non-equivalent control group design

Group	Pre-test	Six-week Intervention	Post-test
Experimental	SSAT, SIPSI, ATLCE	Inquiry-in action	SSAT, SIPSI, ATLCE
Control	SSAT, SIPSI, ATLCE	Conventional demonstration	SSAT, SIPSI, ATLCE

Both comparison groups underwent a pre-test to assess their prior conceptual knowledge on solutions and solubility, their attitudes towards teaching and learning chemistry through experiments, and their science inquiry process skills. This was followed by a six-week intervention. Afterwards, post-tests were administered using the aforementioned three instruments. During the six-week intervention, the experimental (inquiry) group was taught using the Inquiry-in-Action model, while the control (demonstration) group was taught using conventional demonstrations. Both independent groups were taught the same topics, which included types and properties of solutions, factors affecting the solubility of substances, dilute and concentrated solutions, colligative properties, solutions stoichiometry, and solubility curves.

Sampling Technique

Twelve out of the thirty senior high schools in Bong County were selected based on the availability of a chemistry laboratory or suitable space for experimentation. The Lottery Technique was then used to randomly select two groups of four schools to represent the experimental and control groups. All grade eleven students from the selected schools were included in the study sample.

Research Instruments

The SSAT, found in Appendix A, consisted of 25 multiple-choice items exclusively constructed in collaboration with chemistry teachers using past WASSCE chemistry papers from 2000 to 2019. All items were related to solutions and solubility and were selected through consensus among the researchers and chemistry teachers. The SIPSI was adopted from Arnold et al. (2013) and contained 11 items pertaining to the important steps in scientific investigations. Its development aligns with the 4-H Inquiry-in-Action model shown in Figure 1. The SSAT and SIPSI underwent content and construct validation by peers and leaders in the field. Pilot testing of the instruments followed the validation process. The Cronbach Alpha reliability coefficients for internal consistency of the SSAT and SIPSI were determined in SPSS to be 0.700 and 0.708, respectively. These metrics are considered satisfactory for social science research (Fraenkel et al., 2012).

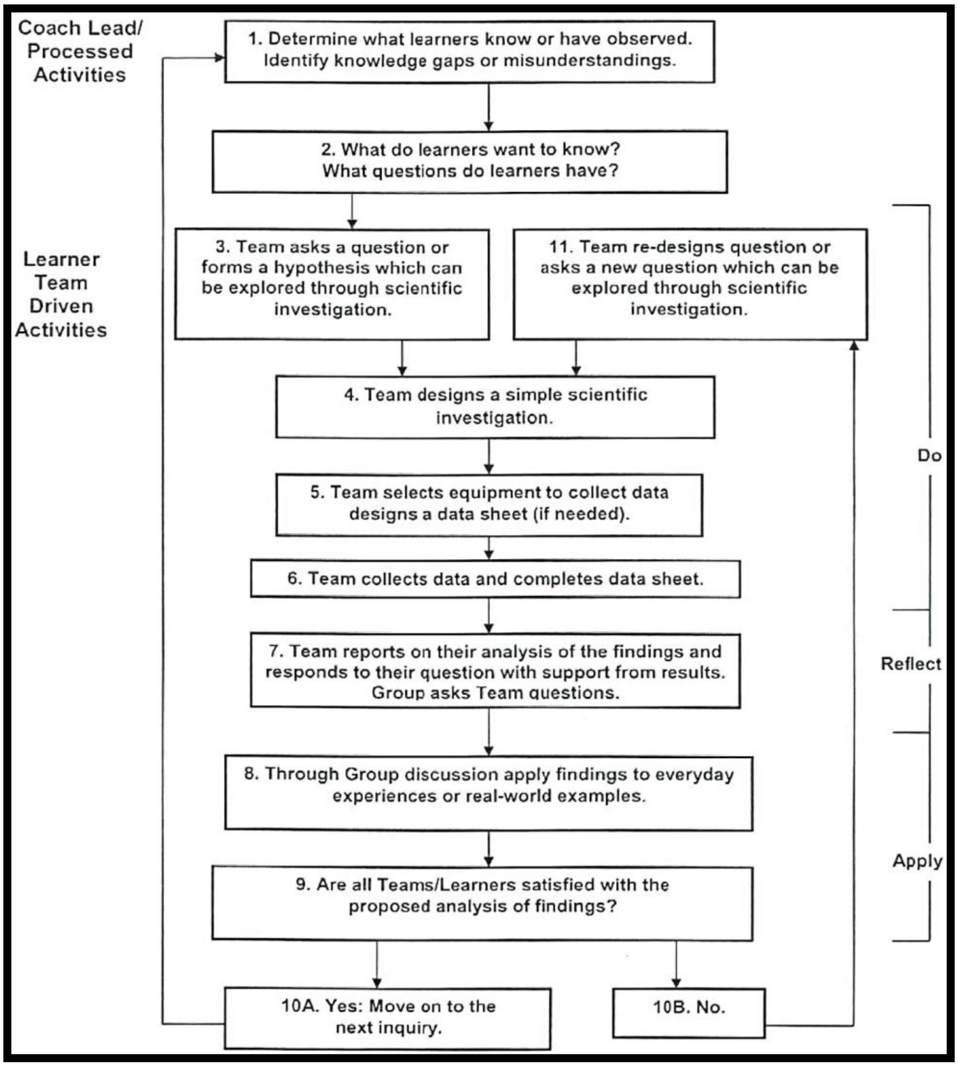

Figure 1. The 4-H Inquiry-in Action Model

Ethical Considerations

To ensure confidentiality, the tests were conducted anonymously. Only the researcher and trained research assistants were responsible for handling the test scripts, survey questionnaires, and inventories. The participants were informed that their test scores would not be used for their regular assessments and evaluations in order to encourage their cooperation and participation. However, they were also informed that they had the freedom to withdraw from the study at any time during the data collection period. This ensured that only willing participants were involved in the process. After completion, the test scripts and survey questionnaires were securely enclosed in labeled A4-sized envelopes and stored in a closed iron cabinet for future disposal.

Data Analysis

The total scores for each student on the SSAT, ATLCE, and SIPSI were calculated using Microsoft Excel. These composite scores were then transferred to SPSS Version 26 for further analysis. The first step in the analysis was to determine the distribution of the scores. Since the data distributions were found to be skewed, non-parametric statistics were used for the analysis. The Mann-Whitney U test was used to compare the differences between the independent experimental and control groups, while the Spearman Rho correlation was used to determine the relationship between the scores of attitude towards teaching and learning chemistry through experiments and science inquiry process skills.

RESULTS AND DISCUSSION

Results

The study results are presented in Tables 3 to 10. Table 3 reveals positive percent differences between the pretest and posttest for both student groups. It also indicates that the factors affecting the solubility of substances section had the highest percentages of students in both groups, with the experimental group achieving a higher score of 70%. Additionally, both groups showed the lowest improvement in the solutions stoichiometry section of the solutions and solubility achievement test. However, the experimental group displayed a higher academic gain of 9.09% compared to the control group's 0.00% in this section. Apart from one section (concentrated and diluted solutions), the experimental group outperformed the control group in all other sections.

Table 3. Quantitative results of students' achievements on the SSAT by subtopics

Subtopic	Experimental mean scores			Control mean scores		
	Posttest	Pretest	%	Posttest	Pretest	%
Types and properties of solutions	35	30	16.67	33	29	13.79
Factors that affect the solubility of a substance	34	20	70.00	29	19	52.63
Dilute and concentrated solutions and units	22	20	10.00	20	17	65
Solutions stoichiometry	12	11	9.09	9	9	0.00
Solubility curves	24	19	26.32	24	20	20.00

Table 4 shows that the control group outperformed the experimental group on the pretest for solutions and solubility achievement by an average of 15.99 points in mean rank. However, this difference is deemed statistically insignificant, with a p-value greater than .05. This implies that the levels of achievement on the pretest were similar between the experimental and control groups prior to the instructional intervention.

Table 4. Results of the experimental and control groups' solution and solubility pre-test

Mann-Whitney *U* test						
Group	**N**	**Sum of Ranks**	**Mean Ranks**	**Mann-Whitney U**	**Wilcoxon W**	**p**
Experimental	185	32572.50	176.07	15367.50	32572.50	.147
Control	182	34955.50	192.06			
Total	367					

Table 5 presents the achievement results for both the inquiry and demonstration groups. The data in Table 5 reveals that the experimental group achieved a positive mean rank that was 36.14 points higher than the negative mean rank. This indicates a learning gain of 36.14 points between the pretest and posttest in the experimental group. The associated p-value of < .05 suggests that this learning gain is statistically significant at a .05 level of significance for the experimental group.

On the other hand, the control group exhibited a higher negative mean rank by 7.96 points, implying a decrease in scores from the pretest to the posttest. However, the difference in mean scores between the pre-and post-test was determined to be statistically insignificant, as indicated by a p-value of < .05 at a .05 level of significance for the control group.

Table 5. Wilcoxon Sign Rank Test Results of the solutions and solubility pre-test and post-test for the comparison groups

Group	Posttest-pretest (Rank)	N	SD	Rank Total	Mean Rank	z	p
Inquiry	Negative Rank	46	12.58	2822.50	61.36	-7.278	.000
	Positive Rank	129		12577.50	97.50		
	Ties	10					
Demonstration	Negative Rank	74		5846.50	79.01	-4.94	.622
	Positive Rank	75	15.60	5328.50	71.05		
	Ties	16					

Table 6 presents the results of the pretest and post-test attitudes of the experimental group. The experimental group exhibits a more pronounced positive change in attitudes on 75% of the sub-scales, specifically in relation to students' preferences and behaviors in chemistry experimentation. A negative change in the motivation subscale (-3.70%) for the experimental group suggests a decrease in motivation. Conversely, the control group displayed a positive change in mean attitude (2.63%), indicating motivation. Both groups demonstrated positive changes in behavior, as evidenced by increased attentiveness and participation in lessons. The experimental group achieved a higher mean attitudinal change (9.46%) compared to the control group (1.21%).

Table 6. Results of the experimental and control groups' attitudes by subscale

	Experimental Group Mean scores				**Control Group Mean scores**			
Subscale	posttest	pretest	Posttest -pretest	%	Posttest	pretest	Posttest -pretest	%
Motivation to Learn Chemistry through Experiments	3.12	3.24	-0.12	3.70	3.51	3.42	0.09	2.63
Preferences in Chemistry Experimentation	3.57	3.41	0.16	4.69	3.70	3.63	0.07	1.93
Behavior in Chemistry Experimentation Class	3.47	3.17	0.30	9.46	3.35	3.31	0.04	1.21
Fears in Chemistry Experiments	3.40	3.16	0.24	7.59	3.34	3.32	0.02	0.81

In Table 7, the positive mean rank is shown to be 17.17 points higher than the negative mean rank, indicating that the post-test mean score is significantly higher than the pre-test mean score. This difference in mean scores between the pre-test and post-test is statistically significant with a p-value of less than 0.01.

Table 7. Results of the experimental groups' science inquiry process skills

		Wilcoxon Signed Rank Test			**Test Statistic**
		N	Sum of Ranks	Mean Ranks	*p*
Posttest-pretest	**Negative Ranks**	65	4599.50	70.76	.001
	Positive Ranks	96	8441.50	87.93	
	Ties	8			
	Total	169			

Table 8 shows a negative mean rank of 29.57 for the science inquiry process skills of the control group, which is higher than the positive mean rank of 26.61. This suggests a higher mean score on the pretest compared to the posttest. The p-value of < .05 indicates that the difference between the mean scores of the control group's science inquiry process skills pretest and posttest is statistically significant at a .05 level of significance.

Table 8. Wilcoxon Signed Rank Test results for the control groups' science inquiry process skills pretest and posttest

		Wilcoxon Signed Rank Test			**Test Statistic**
		N	**Sum of Ranks**	**Mean Ranks**	***p***
Posttest-pretest	**Negative Ranks**	7	207.00	29.57	.000
	Positive Ranks	46	1224.00	26.61	
	Ties	122			
	Total	175			

P < 0.05, the difference is significant.

In Table 9, a correlation coefficient of -.002 indicates a weak negative correlation between the post-test attitudes of the experimental group and their post-test science inquiry process skills. With a p-value of .978, it can be concluded that this weak negative correlation is not statistically significant, based on a significance level of .05. Therefore, there is essentially no evidence of a negative correlation between the attitudes and science inquiry process skills of experimental group students at the posttest stage.

Table 9. Results of correlation between the experimental group's posttest attitudes towards teaching and learning and science inquiry process skills

			Attitudes	Process skills
Spearman's rho	Attitudes	Correlation coefficient	1.000	-.002
		Sig. (2-tailed)		.978
		N	163	163
	Process skills	Correlation coefficient	-.002	1000
		Sig. (2-tailed)	.978	
		N	163	163

Table 10 presents the outcomes of the correlation analysis conducted to evaluate the relationship between the control group's post-test scores of attitudes and science inquiry process skills. The results reveal a correlation coefficient of .282, indicating a weak positive correlation. Additionally, the p-value of .000 signifies that the observed correlation between the control group's post-test attitudes and post-test science inquiry process skills is statistically significant at the .05 level of significance.

Table 10. Results of the correlation between the control group's post-test attitudes toward teaching and learning and science inquiry process skills

			Attitudes	Process skills
Spearman's rho	Attitudes	Correlation coefficient	1.000	.282**
		Sig. (2-tailed)		.000
		N	165	165
	Process skills	Correlation coefficient	.282**	1.000
		Sig. (2-tailed)	.000	
		N	165	176

Table 11 presents the effect sizes observed between independent groups and within related groups. All calculations were carried out using an online calculator for Cohen's d effect size. The range of Cohen's d effect sizes varies from low for the pre-test and post-test SSAT scores of the control group, to medium for both the experimental and control groups, and high for the pre-test and post-test SSAT scores of the experimental group.

Table 11. Sizes of the effect of differences between and within groups

Group	Cohen's d
Experimental and control groups' solutions and solubility achievement pre-test	0.790
Experimental group's solutions and solubility achievement pre-test/post-test	0.840
Control group's solutions and solubility achievement pre-test/post-test	0.010
Experimental group's science inquiry process skills pre-test/post-test	0.360

Discussions

In regard to the subtopics, the higher percentage of achievement scores observed in the experimental group can be partially attributed to the inherent cooperation in the inquiry-in-action approach. It is worth mentioning, however, that solutions stoichiometry stands out as a subtopic of concern. Although both groups demonstrated a weakness in this area, the control group exhibited a more pronounced weakness. This suggests that demonstration may not be the most suitable method for teaching solutions stoichiometry. The overall trend of the results also indicates that experiments, whether conducted through demonstration or inquiry, enhance learners' general conceptual understanding of solutions and solubility.

Despite the experimental group's higher mean score on almost every subscale of the SSAT, as well as their overall greater academic achievement, statistics show that the control group also experienced meaningful learning gains in solutions and solubility. However, the experimental group's maximum mean achievement score (70%) only meets the minimum passing grade stipulated by the Liberian Government for all subjects. On the other hand, the control group's score (52.63%) falls below this minimum pass grade. This suggests the existence and influence of intervening variables that were not considered in this study. The inadequate preparation of teachers and students prior to the intervention may have undoubtedly played a significant role in the learning outcomes.

The 4-H Inquiry-in-action model of teaching chemistry experiments is considered effective for achieving secondary school learners' conceptual understanding of solutions and solubility in this study. However, the results suggest that the potential of the 4-H Inquiry-in-action model to improve conceptual understanding is limited to non-mathematical content. This may indicate a need for a more versatile instructional model for better outcomes in the science classroom. Nevertheless, the overall effectiveness of this inquiry model, as demonstrated in this study, is supported by numerous studies conducted in diverse contexts, such as Balım (2009), Folounrunso and Sunday (2017), Uzezi and Zainab (2017) in Nigeria, Koksal and Berberoglu (2014), and Özgür and Yılmaz (2017) in Turkey, and Hanafi (2016) in Indonesia. Furthermore, the current study's findings on the guided inquiry level of teaching are consistent with the study conducted by Bunterm et al. (2014) in Thailand, which compared structured and inquiry models of teaching. In addition, systematic reviews examining the effects of inquiry-based and didactic modes of teaching science in K-12 students also support the efficacy of the inquiry-based model of teaching science (Constantinou et al., 2018; Minner et al., 2010).

The research literature also includes accounts of critics of the inquiry-based approach to teaching, as well as inconclusive or contradictory findings regarding the effectiveness of this teaching approach. For instance, one study found that the difference in learning gain between the inquiry-based and traditional demonstration approaches was insignificant (Korkmaz, 2012). In a meta-analysis of studies spanning 10 years, it was found that the traditional demonstration of experiments by teachers, where students had limited or no physical manipulation of materials, resulted in higher scores compared to the inquiry-based approach (Furtak et al., 2012). However, whether inquiry or traditional demonstration is superior to the other appears to be a multi-factorial phenomenon.

This current investigation contributes new knowledge by demonstrating that the 4-H inquiry-in-action model may only be effective in ensuring learners' mastery of non-mathematical components of chemistry in general, or the concepts of solutions and solubility specifically. It is important to note that for the majority of student participants in this study, experiments were a new experience in high school, as experimentation is not commonly practiced in the curriculum. Therefore, the mere sight of the apparatus was highly exciting for them, and whether they or their teachers conducted the manipulations of objects in the experiments did not make a significant difference. This highlights the importance of experiments in science teaching.

The unexpected negative motivation in the experimental group may be attributed to boredom resulting from cognitive overload, as the experimental group was required to design the experiments on their own with minimal guidance from teachers. Since the level of guidance is crucial in determining the extent of learning, it is important to exercise caution in providing appropriate guidance rather than minimal guidance.

The higher attitude scores in preferences, behavior, and anxiety among the experimental group indicate that students enjoyed performing the experiments but still had concerns about safety and security. This observation is consistent with previous studies by George-Williams et al. (2018); Henige (2011), and Horsley and Moeed (2018), which also found that students were enthusiastic about participating in learning activities. The present study, which used a scale containing only positively worded items, demonstrated that learners' fear of the laboratory environment decreased over time. This could be attributed to the students' increasing confidence as a result of more demonstrations. However, it is unexpected that the control group had a higher mean score for motivation. One would expect that students would be more motivated when they themselves perform the experiments, rather than the teacher doing the demonstration. However, it is possible that the experimental group experienced boredom due to the cognitive load of designing their own experiments. This practice is unusual and may have resulted in cognitive load. Therefore, the findings of this study highlight the value of traditional demonstrations as well as the limitations of inquiry-based experimentation.

The minimal change in anxiety among the experimental group suggests that safety and security in the laboratory were not major concerns towards the end of the experimentation period. The greater increase in attitudinal change for the experimental group indicates that the inquiry-based approach had a stronger impact on the learners compared to the traditional demonstration.

These findings are consistent with numerous studies conducted using quantitative, qualitative, or mixed-methods approaches. For example, Nicol et al. (2022) found similar effects of guided inquiry experimentation on students' attitudes. The findings of this study are specifically supported by Nedungadi et al.'s (2015) research on the effect of inquiry instruction on students' motivation and interest in chemistry. While many studies favor inquiry instructions, a comprehensive systematic review of published peer-reviewed papers over a ten-year span also supports the effectiveness of didactic forms of instruction in enhancing students' attitudes and other positive outcomes.

The findings of this study differ from those of Montes et al. (2018), in which students were apprehensive about chemistry, resulting in a neutral outcome. Regarding the relevance of chemistry experiments, the observations in this study align with the findings of Kubiatko et al. (2017). Although the students in this study recognized the significance of chemistry, they did not express a desire to become chemists in the future. The findings also suggest that the 4-H Inquiry-in-action model of teaching chemistry experiments had the greatest impact on learners' behavior but had the least motivation to learn chemistry, which could indicate a lack of motivation to pursue a career in chemistry. This implies that while students enjoyed the experimental demonstrations, they were not inclined to become chemists in the future, for reasons that were not investigated in this study.

The Inquiry-in-action model has been shown to significantly improve science inquiry process skills, which aligns with the findings of Şahintepe et al. (2020), Dostál and Klement (2015); and Koksal and Berberoglu (2014). Korkmaz (2012), however, found no significant difference between pretest and posttest science inquiry process skills mean ranks. There was, however, a significant difference between the experimental and control groups in favor of the experimental group. Hardianti and Kuswanto (2017) also observed a significant difference in science process skills when different levels of inquiry were used in a science class. The higher the level of inquiry, the greater the acquisition of science inquiry process skills. It was also noted that the farther apart the levels of inquiry on the inquiry continuum, the greater the acquisition of science inquiry process skills.

On the other hand, contrasting findings have been reported by Ogan-Bekiroğlu and Arslan (2014), who did not establish any significant difference between students' science process skills acquired through inquiry and traditional demonstration methods of teaching. However, it should be noted that this study used models for teaching in the experimental group, while the control group did not. The authors also observed that the control group showed significant increases in identifying variables and stating hypotheses, while the experimental group showed significant increases in these two areas as well as in operational definitions and data and graph interpretations. Although this study did not compare the science process skills of the experimental group with the control group, it is evident that experimentation, whether conducted through inquiry or not, has the potential to enhance students' science inquiry process skills. This study has contributed to the knowledge that the 4-H Inquiry-in-action model enhances the skill to draw graphs of scientific data the most, and the skills to design scientific procedures and correctly record scientific data the least.

The insignificant negative correlation between the posttest attitude of the experimental group and the science inquiry process skills implies that these two variables are somehow positively correlated. The positive relationship between attitude and science inquiry process skills is more pronounced in the case of the control group. This relationship may be more positively correlated for the control group due to the challenges students faced in designing their own experimental procedures. However, this study has demonstrated that the level of inquiry is crucial for both learners' attitudes toward science and their acquisition of science inquiry process skills.

Although the efficacy of the inquiry method of teaching chemistry experiments for enhancing science inquiry process skills has been questioned (Jegstad, 2023) by some who claim that it is inconclusive (Korkmaz, 2012), and by others who observed no significant effect (Bunterm et al., 2014; Hardianti & Kuswanto, 2017), this study found a significant difference in students' science inquiry process skills. The effect size of the inquiry group's pretest and posttest mean scores was found to be high, indicating that beyond statistical significance, this effect size also has practical relevance.

CONCLUSION

This study aimed to assess the impacts of the inquiry-in-action model of chemistry experimentation on the learning outcomes of grade eleven students in Bong County, Liberia. The findings have demonstrated that the inquiry-in-action model is more effective than the conventional demonstration model for teaching chemistry experiments. It enhances academic achievement in the solutions and solubility concept, reduces students' anxiety, and increases their confidence in chemistry experiments. Furthermore, it significantly improves students' science inquiry process skills. There is a generally positive correlation between students' attitudes toward teaching and learning chemistry and their science inquiry process skills. However, this correlation is stronger between students' attitudes towards the demonstration of experiments and their science inquiry process skills than it is between their attitudes towards inquiry-based experimentation and their science inquiry process skills.

It is important to consider the limitations of this study when interpreting the findings and conclusions. These limitations include the fact that only a few schools with the necessary materials or physical space for demonstrations were included. As a result, some demonstrations were conducted outside of a science laboratory. Additionally, the level of motivation among the teachers who implemented the instructional intervention and the prevailing classroom conditions may have varied, potentially influencing the outcomes.

RECOMMENDATION

The results of this study suggest that inquiry-based experimentation is more effective than demonstration in enhancing conceptual understanding of chemistry and other science subjects, improving students' attitudes towards chemistry, and developing science process skills related to experimentation. However, it also suggests that inquiry-in-action should be implemented with an appropriate level of teacher involvement to avoid cognitive overload. Furthermore, the correlation between science process skills and attitudes indicates that the traditional demonstration approach is not completely ineffective, and a combination of demonstration and inquiry-based experimentation may be a viable way to maximize the benefits of science experiments. Therefore, stakeholders in science education should now consider demonstration as a complement to the inquiry-based approach for optimal learning outcomes.

Based on the findings and conclusions, the following recommendations are made to improve high school chemistry education in Bong County and for future studies. The inquiry-in-action method of teaching chemistry experiments should be integrated with traditional experimentation in schools that have sufficient or nearly sufficient laboratory resources. Science teacher training should include the 4-H inquiry-in-action approach. School authorities should prioritize pedagogical content knowledge when recruiting teachers.

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All authors have sufficiently contributed to the study and agreed with the results and conclusions. All authors have read and agreed to the published version of the manuscript.

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Conflict of Interests
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APPENDICES

Appendix A: solutions and solubility achievement test

Solutions and Solubility Achievement Test (SSAT)

Instruction: Answer the following questions by underlining one of the options A, B C or D that corresponds to the correct answer alternative.

1. A solution that contains as much solute as it can dissolve at a given temperature is said to be
   A. Concentrated
   B. Saturated
   C. Supersaturated
   D. Unsaturated

2. Select the best description of a solution with tiny solute particles that cannot be seen under the microscope but are large enough to block light
   A. Saturated solution
   B. True solution
   C. Supersaturated solution
   D. Colloidal solution

3. In a saturated solution at a given temperature, the undissolved solutes are in equilibrium with
   A. The solvent
   B. Dissolved solute particles
   C. The saturated solution
   D. Insoluble solute particles

4. If $10cm^3$ of distilled water is added to $10cm^3$ of an aqueous solution, the concentration of the solution. [2001]
   A. Increases
   B. Decreases
   C. Remains constant
   D. Doubles

5. Which of the following statements is correct? The solubility of
   A. Gases increases with increase in temperature
   B. Gases decrease with increase in temperature
   C. Most solid solutes decrease with increase in temperature
   D. Most solid solutes is constant

6. An unsaturated solution differs from saturated solution at a given temperature because it[2016]
   A. Cannot dissolve more solute
   B. Can hold more solute than it can actually dissolve
   C. Can still dissolve more solute at that given temperature

D. Form crystals more easily on cooling

7. The following factors affect the solubility of a solid in a given solvent except [2013]
   A. Nature of solute
   B. Nature of solvent
   C. Pressure
   D. Temperature

8. A change in temperature of a saturated solution disturbs the equilibrium between the [2015]
   A. Undissolved solute and the solvent
   B. Dissolved solute and the solvent
   C. Dissolved solute and the undissolved solute
   D. Dissolved solute and the solution

9. Which of the following is not a property of solution?
   A. Molecular size
   B. Polarity
   C. Pressure
   D. All of the above

10. A 2.0L of water was used to dissolve 0.88g of sodium chloride, what is the molality?
    A. 1. 0m
    B. 0.0075m
    C. 7.50m
    D. 0.75m

11. A solution of sodium trioxonitrate (iv) contains 10.6g in 250cm^3 of solution. Determine the concentration of the solution. [Na_2CO_3=106.0].[2010]
    A. 0.4mol/dm^3
    B. 1.0mol/dm^3
    C. 10.6mol/dm^3
    D. 25.0mol/dm^3

12. Select the most correct unit equivalence
    A. 1L = 100Ml
    B. 1dm^3= 1000Ml
    C. 1000cm3=1dm
    D. 1dm^3=1L

13. The mass of potassium hydroxide required to make 300.0cm^3 of 0.4 mol/dm^3 solution is [2016]
    A. 26.88g
    B. 13.44g
    C. 6.72g
    D. 3.36g

14. Calculate the mass of sodium hydroxide in 500dm^3 of 0.125mol/dm^3 solution [NaOH]=40g/mol[2002]
    A. 0.0156g
    B. 0.625g
    C. 1.00g
    D. 25.0g

15. A 0.1 mol/dm^3 solution of sodium hydroxide was diluted with distilled water to 0.001mol/dm^3. What is the dilution factor?
    A. 1000.00
    B. 100.00
    C. 10.00
    D. 0.01

16. If 5.00cm^3 of 0.02mol/dm^3 Na_2CO_3 was diluted with diluted with distilled water to obtain 250cm^3 solution. What is the concentration of the resulting solution?
    A. 0.004 mol/dm^3
    B. 0.02 mol/dm^3
    C. 0.20mol/dm^3
    D. 0.40mol/dm^3

17. If 20cm^3 of distilled water is added to 80cm3 of 0.5mol/dm^3 hydrochloric acid, the concentration of the acid will change to [2000]
    A. 20mol/dm^3
    B. 0.40mol/dm^3
    C. 2.00mol/dm^3
    D. 5.00mol/dm^3

18. If 0.20mol/dm^3 NaOH was evaporated to yield 5.0g of solid NaOH, calculate the volume of NaOH used. [Na=23.0, O=16.0, H=1.0][2014]
    A. 600cm^3
    B. 625cm^3
    C. 1000cm^3
    D. 1600cm^3

19. Solubility is practically applied in [2015]
    A. Fractional distillation
    B. The determination of pH
    C. The determination of saturation in hydrocarbons
    D. Solvent extraction

20. If 0.2g of a salt is required to saturate 200cm^3 of water at room temperature, what is the solubility of the salt? [2017]

    A. 0.2g/dm^3
    B. 1.0g/dm^3
    C. 2.0g/dm^3

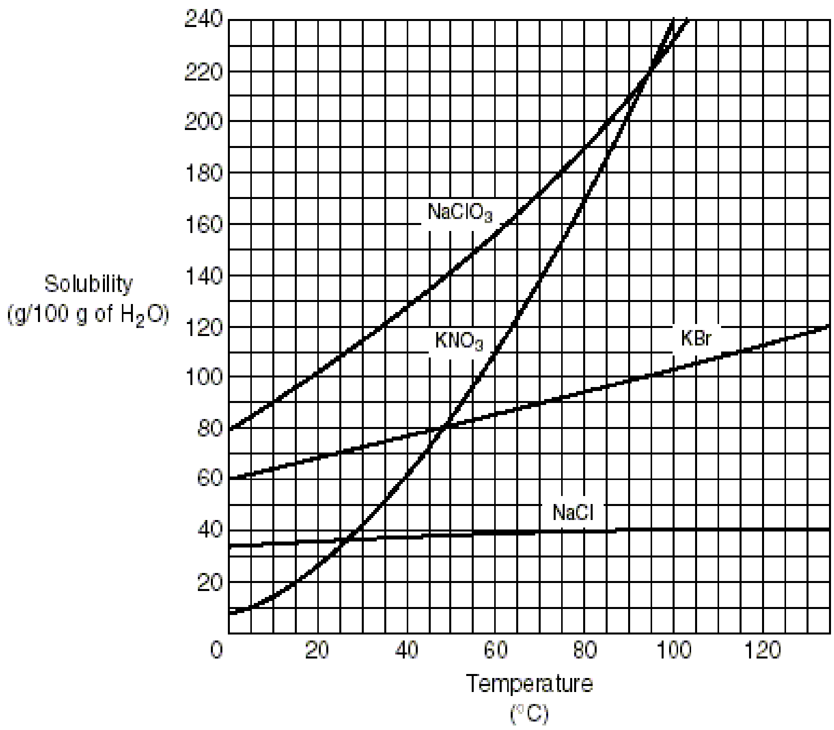
D. 5.0g/dm³

21. On evaporation to dryness, 250cm³ of saturated solution of salt X with relative molar mass 101 gave 50.5g of the salt. What is the solubility of the salt?
    A. 1.0mol/dm³
    B. 20mol/dm³
    C. 4.0mol/dm³
    D. 5.0mol/dm³

22. Solubility curve can be applied in the determination of the [2017]
    A. Amount of crystals formed
    B. Amount of solvent that can be recovered
    C. Amount of solid drugs in a given solution
    D. Temperature of the solution

PLEASE TURN OVER THE PAGE

Consider the following solubility curves



23. Which of the following deductions could be correctly made from the graph?

    A. The solubility of NaCl is not affected by change in temperature
    B. The solubility of $NaClO_3$ is decreases with increasing temperature
    C. KBr is most soluble among the salts
    D. KNO_3 is least soluble among the salts

24. The solubility of $NaClO_3$ at 80^0C is

    A. 30 g/100g of H_2O

B. 70 g/100g of H_2O
C. 120 g/100g of H_2O
D. 90 g/100g of H_2O

25. What mass of KBr crystal will form when cooled from 115 ^{0}C to 70 ^{0}C

A. 40g

B. 65g
C. 20g
D. 15g

END
Thanks for your kind cooperation

Appendix B

Attitude towards teaching and learning chemistry by experimentation (ATLCE) survey questionnaire

Hello, my name is Author 1, I am a PhD student reading chemistry education at the African Centre of Excellence for Innovative Teaching and Learning Mathematics and Science, University of Rwanda. I am kindly asking you to assist me in collecting relevant data for my research by filling in this questionnaire. My research is titled "The Influence of Inquiry-based Chemistry Experimentation Instructional Techniques on the Academic Performance of Grade Eleven Students in Bong County, Liberia". I intend to use the information you provide in this questionnaire to compare the students' attitudes towards teaching and learning of chemistry experimentation by inquiry-based and traditional methods.

Section A: Background information of respondent

1. Age: ----------
2. Sex. (Please mark a tick (√) in the rectangular box below the option applicable to you)
   a. Male: ☐
   b. Female: ☐
3. Name of School: ______________________________
4. Are you a new student in this school?
   Yes ☐ No ☐
5. If no, for how many academic semesters have you been in this school
   1 semester ☐
   2 semester ☐
   3 semester ☐
   4 semester ☐
   5 semester ☐
   More than 5 semester ☐

Section B: Attitude measuring scale

Below is a scale that has statements/sentences called items in the middle. Carefully read each statement and then circle (○) one of the options (SD, D, N, A, SA) on the right of the scale that most appropriately applies to you under the response column. In the response column,

SD = Strongly Disagree
D = Disagree
N = Neutral
A = Agree
SA = Strongly Agree

Item No.	Item	Responses				
		SD	D	N	A	SA
A.	**Students' Motivation to Learn Chemistry by Experimentation**					
1.	Chemistry experiments are exciting	SD	D	N	A	SA

Item No.	Item	Responses				
		SD	D	N	A	SA
2.	Chemistry experiments are interesting	SD	D	N	A	SA
3.	Chemistry experiments provide better understanding of the concepts.	SD	D	N	A	SA
4.	I enjoy learning in a chemistry experimentation class	SD	D	N	A	SA
5.	My teacher made me to like chemistry experiments	SD	D	N	A	SA
6	I would like to be a chemist	SD	D	N	A	SA
B. Students' Preferences in Chemistry Experimentation						
7.	I prefer experiments to theoretical chemistry lessons	SD	D	N	A	SA
8	I prefer to solve chemistry problems through experiments	SD	D	N	A	SA
9.	I prefer the explanation of the concept before the chemistry experiments	SD	D	N	A	SA
10.	I prefer to do chemistry experiment in groups to individual work	SD	D	N	A	SA
11.	I prefer to do chemistry experiments myself to watching somebody do it and I watch	SD	D	N	A	SA
12.	I prefer to design experiments myself with little teacher guidance	SD	D	N	A	SA
13.	I prefer my peer to teach me in chemistry experiments	SD	D	N	A	SA
Students' behavior in Chemistry Experimentation Class						
14.	I attend chemistry experiments classes regularly	SD	D	N	A	SA
15.	I am very attentive in the chemistry experimentation lessons	SD	D	N	A	SA
16.	I ask questions whenever I don't understand a procedure or skill	SD	D	N	A	SA
17.	I write down important points for future reference in chemistry experimentation classes	SD	D	N	A	SA
18.	I apply ideas from chemistry experiments to everyday experiences	SD	D	N	A	SA
Students' Anxiety in Chemistry Experiments						
19.	Designing a chemistry experiment is easy	SD	D	N	A	SA
20.	Chemistry experiments can be completed within a short time	SD	D	N	A	SA
21.	Chemistry experiments are safe	SD	D	N	A	SA
22.	I am confident when demonstrating chemistry experiments	SD	D	N	A	SA
23.	I am fearless to touch chemicals in chemistry experiments	SD	D	N	A	SA
24.	Chemistry experiment is a good use of my time	SD	D	N	A	SA

Item No.	Item	Responses				
		SD	D	N	A	SA
25.	Relating experiments to theory in chemistry is easy for me	SD	D	N	A	SA

Appendix C: Science Inquiry Process Skills

Instructions for handing in the survey sheet

Thank you for completing this survey sheet. Please carefully go over the responses to be sure that you have selected the right responses. Thereafter, please make sure to hand in the survey sheet to the research assistants. Once more, I thank you for your time and kind cooperation.

Appendix G: Science process skills inventory

Section A: Background information of respondent

1. Age: ----------
2. Sex/gender (Place a tick in one of the boxes as applicable to you).
   c. Male: ☐
   d. Female: ☐
3. Name of school: ____

Section B: science inquiry process skill scale

Below is a scale that has statements/sentences called items in the middle. Carefully read each statement and then circle (○) one of the options (**N, ST, U, A**) on the right of the scale that most appropriately applies to you under the response column. In the response column,

N = Never
ST = Sometimes
U = Usually
A = Alway

Item No	Item	Responses			
1	I can use scientific knowledge to form a question	N	ST	U	A
2	I can ask a question that can be answered by collecting data	N	ST	U	A
3	I can design a scientific procedure to answer a question	N	ST	U	A
4	I can communicate a scientific procedure to others	N	ST	U	A
5	I can record data accurately	N	ST	U	A
6	I can use data to create a graph for presentation to others	N	ST	U	A
7	I can create a display to communicate my data and observations	N	ST	U	A
8	I can analyze the results of a scientific investigation	N	ST	U	A
9	I can use science terms to share my results	N	ST	U	A
10	I can use models to explain my results	N	ST	U	A
11	I can use the results of my investigation to answer the question that I asked	N	ST	U	A

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