Flipped, Open Inquiry, and Demonstration Practicals Contrasted: Effects on High School Chemistry Learning Achievement and Intellectual Curiosity

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Abstract: Experimentation is rare in most West African high schools due to the absence of functional science laboratories. Chemistry teachers more often resort to demonstration, which may limit curiosity in science learners and negatively affect general learning outcomes. This study examines the effect of demonstration, guided inquiry, and flipped practical experimentation on the chemistry achievement scores, and intellectual curiosity of grade eleven students in Bong County, Liberia. The Non-equivalent control group design was used, with 340 students in six high schools constituting a cluster random sample. Multivariate Analysis of Covariance (MANCOVA) was used for inferential statistical analyses. Results showed that the three methods are unequally effective in enhancing conceptual understanding of chemistry; there was a significant difference in the effectiveness between the inquiry-based and the flipped experimentation, in favor of the flipped practical, which was also the most effective. Learners' curiosity did not depend on experimental approach. The outcome of this study implies that the use of multimedia embedded experiments in teaching science needs to be implemented since it arouses learners' curiosity.

Keywords: Demonstration, Experimentation, Flipped practical, Open-inquiry, Intellectual curiosity.

INTRODUCTION

Science education has played a pivotal role in the amazing advancement of technology and innovations in robotics, medicine, engineering, and environmental science, and in that way, it has contributed to addressing real-world challenges. In fact, leaders in the field have emphasized a strong positive correlation between national development and a sound science and technology education (Gongden, 2021). Chemistry is the central science (Brown *et al*., 2012), and by reason of this fact, no innovation in technology is devoid of it. Notwithstanding, the research literature bears evidence of traditional chemistry teaching practices that are predominantly textbook dependent, potentially limiting the aspiration for innovation in teaching. Besides, the textbooks may not relate the science content to real-life situations, which has the propensity to bore learners, leading eventually to continuous unsatisfactory academic performance (Cao, Xu, & Hu., 2022). Therefore, researchers are calling for practical, innovative, participatory, and interactive teaching approaches that enhance intellectual curiosity and achievement test scores.

Intellectual curiosity is born out of a profound desire to learn and leads to questioning to acquire new knowledge and skills. It is a habit of mind, considered a useful scientific process (Bathgate *et al*., 2014; Gruber & Ranganath, 2019), that translates into a sustained attention span and motivation to engage in inquiry tasks in an educational setting. Learners' sense of curiosity is also a predictor of learning outcomes (Gurning & Siregar, 2017; Abakpa *et al.,* 2018; Kadek *et al.,* 2020). Tessa *et al*'s (2018) study of the effects of different levels of inquiry on the curiosity levels of seven to nine-year-olds revealed a dependence of the levels of knowledge acquisition on the kids' curiosity. Notwithstanding, high school students' curiosity and interest in chemistry are dwindling due to the teaching strategies (Chrappan & Bencze, 2017; Said *et al*., 2016; Potvin & Hasni, 2014). This gradual loss of interest has translated into a drastic reduction in the number of chemistry majors at most universities around the world (Bicer & Lee, 2019; Halim *et al.,* 2018; UNESCO, 2015).

Questions are being raised about the effectiveness of science teaching methods, generating considerable interest in science education research (Ganyaupfu, 2013). The design and execution of a highly engaging and interesting lesson is critical to raising learners' curiosity, sustaining their attention span, and achieving learning gain (Gruber & Ranganath, 2019). Fortunately, the teaching of practical science subjects provides a lot of opportunities for developing curiosity in learners (Sthephani & Yolanda, 2021). Generally, experimentation allows learners to construct long-lasting knowledge, develop science process skills, and leads to intrinsically motivated learning.

While there is overwhelming evidence in support of guided inquiry-based experimentation (Nicol, 2021), there is a dearth of empirical studies on open inquiry experimentation. In a study that investigated the effectiveness of guided inquiry and structured

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inquiry-based teaching approaches involving 239 Thai students from grades seven to ten, Buntern *et al.* (2014) found that the guided inquiry-based teaching yielded a significantly higher mean score. Similarly, when the effects of three variants of inquiry-based approaches; the structured, guided, and open inquiry-based approaches, on academic achievements were studied, the guided inquiry was demonstrated to be the most effective, followed by the structured approach (Udo, 2010). In an intervention study that involved 62 high school students, who were taught electrochemistry using experimentation, there were more misconceptions in the control group, taught by traditional demonstration after intervention, than in the experimental group that was taught using the guided inquiry approach (Sesen &Tarhan, 2013). The aforementioned studies demonstrate the versatility of inquiry interventions across different levels of education. Inquiry promises to be the way out of science teaching challenges.

A systematic review of published findings on inquiry-based teaching approaches from 2005 to 2015 concluded that the guided inquiry-based teaching approach is superior to other inquiry approaches (Aktamis & Ozden, 2016). Nonetheless, findings have also shown that there is no need to replace demonstration with inquiry-based teaching. For instance, in the study of Yiridim and Berberoglu (2012) there was no significant difference between the inquiry and the demonstration approaches. In fact, a few studies have found that demonstration leads to better learning indicators. Typical is the study by Furtak *et al*(2012), who found a significant difference, with a meaningful effect size, between demonstration and inquiry approaches in favor of demonstration.

These findings suggest that the research on the effects of inquiry and demonstration modes of teaching is inconclusive. It further suggests probing into the research contexts and designs with the view to finding out the cause(s) of these nuances. In the observation of Bolte *et al*. (2013), high-achieving learners do not prefer inquiry-based teaching approaches because they are time consuming, and put a lot of burden on learners' thinking. Critics of guided inquiry have even suggested that inquiry-based teaching causes cognitive overload and impairs learning. In fact, Tan *et al* (2014) expressed that most of the studies that give a higher rating to the inquiry-based approach over traditional demonstration have smaller samples. Therefore, findings of such studies should not be generalized.

The integration of technology into classroom teaching has opened the floodgates to the proliferation of online teaching platforms, which have been used to maximize learning gains, enhance creativity, and innovations in learners (Wei *et al*., 2020). They constitute a paradigm shift in delivering learning content in an engaging manner (Fletcher & Griffiths, 2020). Flipped classrooms, an innovative teaching method that mostly incorporates multimedia, have been one of the most researched areas in science education since it was proposed in 2007. It offers a suitable alternative to the exclusive classroom learning, where learners take ownership of their learning out of the classroom. Flipped classroom prepares learners for subsequent classroom engagement with the teacher. It has been found to enhance self learning abilities, and learning curiosity (Kurnianto *et al*., 2020). In other words, it cultivates intrinsic motivation in the learner.

The results have however been as inclusive as the inquiry-based model. For instance, when the experimental group, which was given a video lecture, followed by an in-class interaction, was compared with the control group, which was exposed to video lecture and simultaneous classroom interaction in a study of the effects of these methods of teaching on academic performance of 7th graders, there was significant difference between the groups, with the experimental group attaining the higher mean score (Semab & Naureen, 2022).

Apart from the positive effect on academic performance, the flipped classroom model was found to promote communication and collaboration among learners (Murat & Cam, 2021). Also, in an experimental study involving elementary school learners, the flipped classroom model was found to enhance critical thinking and general learning outcomes (Kurnianto *et al*., 2020). In an applied linear algebra course taught by flipped and traditional modes, results showed that the flipped model yielded greater formative assessment scores, but there was no significant difference in the summative assessment scores (Love *et al*., 2014). However, in Gelgoot *et al*.'s (2020) study on talented students, there was no meaningful difference in academic achievement. In fact, the students rated the traditional teaching higher for organization, enjoyment, and clarity. In sum, the flipped classroom has been demonstrated to be a valued, innovative teaching strategy that is worth studying further in other contexts and cultures.

Despite the evidence of many documented research studies about flipped classroom and inquiry-based teaching in different contexts and cultures, these studies have rarely focused on high school learners. Besides, quasi-experimental studies that explore the influence of inquiry teaching and flipped classroom on intellectual curiosity are still scarce. This study seeks to address these gaps in knowledge by investigating the influence of three different chemistry experimentation approaches; the flipped, open inquiry, and demonstration practicals on learning achievement and intellectual curiosity.

THEORETICAL FRAMEWORK

This theory that underpins this study is constructivism, which has two principal variants; the cognitive constructivism founded by Jean Piaget, and the Social Constructivist theory, founded by Lev Vygotsky. Piaget's cognitive constructivism holds that individual learners learn by actively incorporating a new knowledge into an existing knowledge (Amineh & Asl, 2015). Lev Vygotsky's social constructivism holds that learning is achieved foremost through social engagement before personal internalization (Khan *et al.*, 2011). This theory emphasizes social interaction between the learner and the teacher, and among the learners themselves.

In both flipped and open-inquiry practicals, some of the teacher's role is shifted to the learners and the teacher is not the only source of knowledge. Both approaches view learning as the result of the co-construction of knowledge by teachers and learners. In the case of the flipped practical, learners go to the classroom knowing the topic to be learned, and prepared for participation in class. In either of these approaches, the teacher essentially acts to make clarifications, correct misconceptions, and lead discussions (Sherbino *et al.*, 2013). In this way, both flipped practical and open inquiry mirror constructivism.

In Liberia, the high school national curriculum emphasizes competency-based science education, and for the teaching of science subjects, this implies hands-on science experimentation. However, experimentation is rare in high schools due to either the absence of laboratory facilities or a short supply of laboratory resources. Hence, a few schools that have science laboratory facilities resort to demonstration, where the teacher does all the manipulations of materials and ideas on a rostrum in front of the class while learners only watch (Chan *et al.*, 2015). This mode of science teaching may limit curiosity in learning science and negatively affect general learning outcomes. It is not entirely surprising, therefore, that the outcome of the Liberian candidates in the West African Senior Secondary Certificate Examinations (WASSCE) in chemistry has not been satisfactory in recent years. The pass rate in chemistry from the West African Examinations Council (WAEC) is shown in Table **1**.

Table 1: Results of the Pass Rate for Chemistry in the WASSCE

Year	Pass Rate (%)
2020	13.51
2021	5.33
2022	15.35
2023	31.70

Source: WAEC(2020, 2021, 2022, 2023).

The Liberian Ministry of Education has attributed this continued unsatisfactory performance to the methodology of teaching (MOE, 2022). On the basis of the pass rates in Figure **1**, there is a compelling need for leveraging innovative teaching strategies that would raise learners' curiosity and hopefully enhance their learning of the highly abstracted chemistry contents. Therefore, this study focuses on determining the effect of three chemistry experimentation teaching approaches: demonstration, guided inquiry, and flipped practical experimentation on chemistry academic achievement scores and curiosity. Accordingly, the study seeks to answer the research question: Which approach of chemistry experimentation yields the most desirable learning outcomes? To further focus the research, the following research hypotheses were tested.

H_{01}: There is no statistically significant difference in the chemistry achievement post-test mean scores across the three independent groups.

H_{02}: There is no statistically significant difference in the intellectual curiosity post-test mean scores across the three independent groups.

METHODS

The Non-equivalent control group quasi-experimental design was used. This quantitative research design permits the use of intact groups of subjects (Frankael *et al.*, 2012). Therefore, intact classes were assigned as experimental and control groups. This was a prudent step to avoid disrupting the school sessions, as it was the third week of instruction in the academic semester. Participants were grade eleven students, aged 11 to 17, 58.6% of whom were males. Pre-intervention exercises included a six-week teacher development workshop conducted separately with the teachers in their respective teaching approaches, the construction and validation of the research instruments for data collection, and the pilot-testing of the validated instruments. The sessions were separately conducted for teachers to avoid program contamination. A six-week instructional plan was agreed upon on the last day of training.

The Reaction Rates Achievement Test (RRAT) in Appendix B was a 25 multiple choice item researcher-designed test, with items carefully selected from the prescribed chemistry textbook (Geetanji & Singh, 2023) for grade eleven and the WASSCE past papers. The Intellectual Curiosity Inventory (ICUR) in Appendix C, comprising sixteen – items, was adopted from Herwin and Nurhayati (2021). Both instruments were validated for appropriateness of content and constructs by knowledgeable peers in science education. Thereafter, they were pilot-tested with forty grade eleven students in high schools other than those included in the sample to establish their reliability coefficients. The reliability coefficients were found to be .83 and .79, for the RRAT and the ICUR, respectively, which represent fairly reliable instruments (Frankael, *et al*., 2012).

Once the reliability was ascertained, pretests were administered to determine the baseline of the variables of interest. These were followed by the instructional intervention, which spanned six weeks and was climaxed by a posttest. The teachers were being observed and given feedback at the end of every lesson. In addition, there were weekly debriefing sessions at the end of each week of instruction, meant to provide suggestions for improvement in subsequent lessons. Steps taken to ensure internal validity of the results included that equivalent tests were administered to control for pretest sensitization, ensuring the same examiners and similar testing conditions. Essentially, since the same topics were taught, any difference in the outcome variables would supposedly be due to the method of teaching.

In the demonstration class, a manual that contained the experimental procedures was distributed to students ahead of the experiments. The teacher performed the experiments, following the procedures as outlined in the manual, while students only watched the demonstrations. The teacher, at a slow pace, did the data collection and analysis on the blackboard, and students took notes. Students were encouraged to ask questions if they did not understand anything. In addition to regular comprehension checks, the teacher evaluated the students at the end of every lesson by making further comprehension checks via questioning.

In the open inquiry class, students in cooperative groups of four or five were given the title of the experiment, the question that the experiment was addressing, the apparatus, and the reagents. The students were required to brainstorm on the possible procedure, make a diagram of the procedure, then proceed with setting up the experiment, make observations, collect data, analyze the data, and draw conclusions based on the findings. The teacher intervened minimally with hints and suggestions, and as much as possible refrained from providing direct answers to questions raised. The students were responsible for figuring out everything for themselves. At the end of the lesson, the teacher led a discussion, using the Socratic method to provide clarity on challenges they faced in suggesting a procedure and setting up the experiments. The teacher asked evaluation questions at the end of each lesson.

The flipped practical had two stages; in the first stage, the students were handed prescribed multimedia that explained the experimental procedures, principally YouTube videos, to study at home on a day preceding the second stage in the classroom. The classroom interaction took the form of cooperative learning, in a guided inquiry and experimentation. The open inquiry offered students in small cooperative groups total autonomy, from determining the experimental procedure to setting up the experiment,

Figure 1: Photograph of the traditional demonstration of chemistry experiments.

Figure 2: Photograph of cooperative groups of students in the open inquiry experimentation.

writing down the observation, and drawing a conclusion. In the demonstration approach, students were not grouped, but were seated in a traditional fashion while they watched the demonstration of the experiments by the teacher. Students in each of the three conditions had the experimental procedures in a pamphlet given to them.

POPULATION AND SAMPLE

The accessible population for this study was 1,754 grade eleven students, from which a sample of 340 was selected by the cluster random sampling technique. This sample size is considered statistically appropriate according to the calculation by Krejcie and Morgan (1970) at 95% confidence level and 5% margin. Out of a total of 31 high schools in Bong County, twelve schools were initially selected because they had laboratory facilities or a conducive environment for experimentation. Afterwards, six schools were randomly selected from the twelve to constitute the sample of schools in this study. Two schools were randomly assigned to each of the three conditions; demonstration, open inquiry, and flipped practicals. One class was selected in each of the selected six schools. The students in these six schools constituted the sample and subject of the study. These students are being taught using a competency-based curriculum that was adopted by the Liberian Ministry of Education in 2018.

DATA COLLECTION PROCEDURE

Once the study was approved by the Bong County Education Officer, the nature and aim of the study were explained to the school administrators of the six sampled schools. Thereafter, pilot testing of the instruments was conducted in schools that did not belong to the sample. For informed consent, participants took turns to read the information contained in the consent sheet, while researchers provided a detailed explanation. When it was obvious

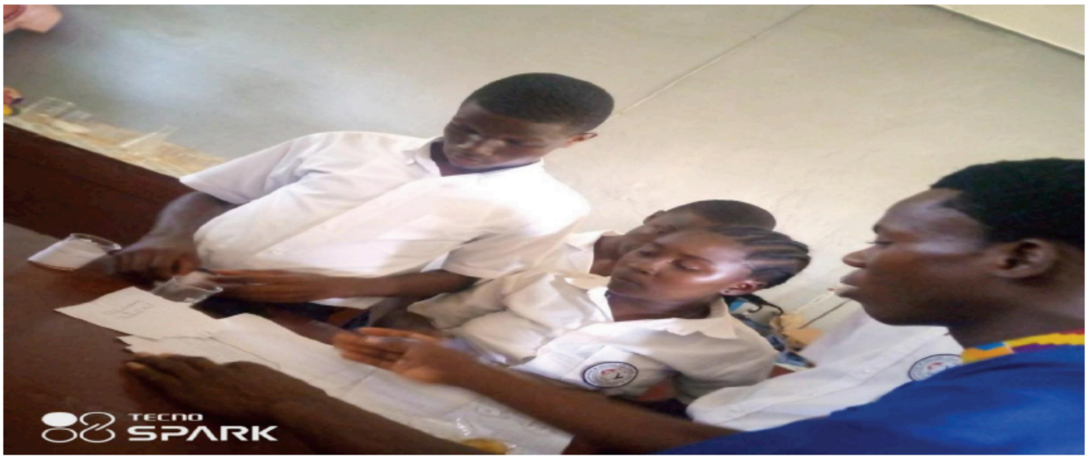

Figure 3: Photograph of students in a guided inquiry experimentation.

that participants understood the contents of the consent, each participant was asked to sign it if they wanted to participate in the research. Participants were informed that they could quit if they chose to at any point in the process of data collection. Also, participants were assured that the scores in the test would not be used for their assessment, but would rather solely be used for the research. This ensured voluntary participation. The test scripts and filled-out questionnaires were securely enclosed in an A4-sized envelope, and were handled only by the research team.

DATA ANALYSIS

The test scripts and questionnaires were coded, and the scores on the tests and responses from the questionnaires were fed into a Microsoft Excel spreadsheet. Afterwards, the responses from the Likert scale questionnaire were converted into their numerical equivalents as follows: Strongly disagree (SD) = 1, Disagree (D) = 2, undecided (U) = 3, Agree (A) = 4, Strongly disagree (SA) = 5. The composite total for each case was computed in Excel and transferred into the Statistical Package for Social Sciences(SPSS) software for analysis.

The tests for normality of distributions were run to determine the shape of the data. With the exclusion of outliers, the distribution was essentially normal by indication of a Shapiro-Wilks statistic of .0734. Other conditions for using the Multivariate Analysis of Covariance (MANCOVA), including the multivariate normality of the dependent variables, a linear relationship between dependent variables or each independent variable, homogeneity of variance-covariance matrices, and linearity in the dependent variables, were satisfied as shown in Table **2**. This, and the fact that there was one independent variable (experimentation) at three levels, and two dependent variables (achievement scores and curiosity), informed the use of the one-way MANCOVA to compare the means across the three independent groups, while controlling for the possible confounding effect of pretest scores as covariates. However, based on unequal group numbers, the Pillai's Trace statistic, rather than the Wilks Lambda statistic, was used to interpret the multivariate test result (Pallant, 2012). Analyses were conducted using the Statistical Package for the Social Sciences at a 95% level of confidence (α = .05).

Table **2** shows values of major statistical indicators that are relevant to the choice of analysis of the generated data in this study. First, the p-values of Box's test of variance and covariance for both dependent variables are > .05, indicating that the variance and covariance of the RRAT and ICUR scores were equal across the three independent groups. Second, the indicated p-values of the Levene's Test for equality of error variances for both dependent variables are > .05, implying that the variances of the comparison groups are similar, a necessary condition for using MANCOVA. The Pillai's Trace value of .037, being close to zero, suggests that the groups are not quite different on their outcome variables.

RESULTS AND DISCUSSION

The following are the results obtained in the analysis, their interpretations, and discussions.

Table **3** presents the means and standard deviations of the variables of interest. The mean scores in the RRAT range from 56.27 for the inquiry-based method, 59.24 for the demonstration, to 63.33 for the flipped practical session. These figures start to point to a meaningful difference in the mean scores, especially between the flipped practical and open-inquiry modes of experimentation. The standard deviations indicate more spread of the demonstration scores (15.43) than those of the inquiry (12.74) and flipped practical (12.31), with the flipped practical method scores being the least spread. These figures demonstrate that the greater the spread, the lower the mean scores.

The mean ICUR scores range from 59.11 for the demonstration and 60.38 for the inquiry to 62.59 for the flipped practical, with the mean scores for demonstration being the least. Again, the standard deviations indicate that the scores of the demonstration group are the most spread, but the lowest mean score.

Table 2: Results of Statistical Indicators of some Prerequisites for MANCOVA

INDICATORS	Value	F	df1	df2	sig
Box’s test of equality of variance matrices	10.223	1.689	6	2794503	.119
Levenes’ test for equality of error variances (RRAT)	-	2.075	2	337	.126
Levenes’ test for equality of error variances(ICUR)	-	2.128	2	337	.121
Multivariate test (Pillai’s trace)	.037	3.137	4.00	670.00	.014

Table 3: Results of Descriptive Statistics of the Posttest Scores

Experimentation		Mean	Std. Deviation	N
RRAT	Open inquiry-based	56.47	12.74	110
	Flipped practical	63.33	12.31	116
	Demonstration	59.24	15.43	114
	Total			**340**
ICUR	Open inquiry-based	60.38	13.80	110
	Flipped practical	62.59	14.64	116
	Demonstration	59.11	15.79	114
	Total			**340**

The values of standard deviations in both RRAT and ICUR, ranging between 12 and 16, are indicative of appreciable variations, thus representing a multi-level character of the students in both groups.

Table **4** displays the between-subjects effects for the covariates and the posttest. All the p-values (indicated by sig) for the RRAT and ICUR as covariates are >.05. This means that there is no statistically significant difference between the chemistry achievement and the intellectual curiosity pretest scores, implying that the groups were equal on the levels of chemistry knowledge and intellectual curiosity before the intervention. Judging from the mean squares, the posttest means are higher than the pretest for all three teaching approaches. This is the case for both the RRAT, and the ICUR. This means that each of the three approaches enhanced conceptual understanding of chemistry, although to varying extents. However, the three methods influence curiosity to similar extent. The size of the effect of differences between the groups' pretest mean scores range between .001 and .003, indicating that the difference between the pretest scores actually range from .1% to .3%. Also, the difference between the groups' intellectual curiosity posttest mean scores is only .3%. However, the differences between the groups' chemistry achievement posttest mean scores are 3.4%, which is interpreted as being nearly medium (Cohen, 1988). Therefore, these pretest results show that the outcome variables are not influenced by the covariates (pretest scores), since they show no significant difference between the groups. Following is the testing of the hypotheses.

TESTING OF THE HYPOTHESES

Hypothesis One

H_{01}: There is no statistically significant difference in the chemistry achievement posttest mean scores across the three independent groups.

Testing this hypothesis requires considering the p-values (designated by sig) for the posttest RRAT in Table **4**. Since the p-value is <.05, the level of significance, it implies that there is a significant difference in the RRAT mean scores at this level of significance. Therefore, there is sufficient evidence to reject the null hypothesis.

Hypothesis Two

H_{02}: There is no statistically significant difference in the intellectual curiosity posttest mean scores across the three independent groups.

Table 4: Results of Test of between Subjects Effects

Dependent variables		Sum of squares	df	Mean square	F	sig	Partial eta squared
Covariate 1 RRAT pretest	RRAT	91.684	1	91.684	.497	.481	.001
	ICUR	106.789	1	106.789	.487	.486	.001
Covariate 2 ICUR pretest	RRAT	165.379	1	165.379	.897	.344	.003
	ICUR	33.417	1	33.417	.152	.696	.000
posttests	RRAT	2180.478	2	1090.239	5.912	.003	.034
	ICUR	233.583	2	116.791	.533	.587	.003

To test this hypothesis, reference is made again to Table **4**, which shows a p-value for the posttest ICUR >.05. Since the p-value is greater than .05, the level of significance, there exists no significant difference in the posttest intellectual curiosities of the three groups. Therefore, there is no statistical evidence to reject the null hypothesis. To determine which group(s) are significantly different, reference is made to the results of post hoc analysis.

With respect to the RRAT, the post hoc analysis results in Table **5** reveals the details of the existing significant difference(s) in pairs of the three groups. Table **5** shows that p-values for the RRAT are all >.05 for the comparisons between the demonstration and inquiry-based, demonstration and flipped practical experimentation. This means that there are no significant differences between these groups. However, the comparison between the inquiry-based and flipped practical is statistically significant, as indicated by a p-value < .05. This implies that the only significant difference lies between the inquiry-based and flipped practical methods of experimentation. Also, Table **3** shows that this difference is in favor of the flipped practical. In other words, the efficacy of the methods in enhancing academic performance in chemistry is in the order flipped practical > demonstration > open inquiry experimentation. Although there is no significant difference in intellectual curiosity, the order of size of the influence of teaching on intellectual curiosity is: flipped practical > open inquiry > demonstration.

DISCUSSION OF RESULTS

The three experimental approaches have proven to be effective to different extents in enhancing students achievements. However, the findings in this study indicate that the flipped practical yields the best academic achievement in chemistry. The eta squared effect size of 3.4% implies that the variance in academic performance is small (3.4%), which is believed to be due to the teaching approach. Although the open inquiry practical is shown to have the lowest mean, the combination of multimedia and the guided inquiry activities that are embedded in the flipped practical could have accounted for the increased academic performance. This probably means that this combination yields a greater positive effect than any of the two. In addition, this study has contributed to knowledge by demonstrating that the more actively involved the learners are in a scientific inquiry, the better they learn, and the better the academic performance. The findings in this study support those of Semab and Nauren (2022) although their study was conducted on seventh graders and was limited to only two groups.

However, the results of this study contrast those of Love *et al.* (2014), which involved college students, in which no significant mean difference in the academic performance of flipped and traditional classroom learners was found. The results in this present study also contradict Gelgoot *et al's* findings in a study of talented students in which the authors found no significant difference in academic achievement. In sum, these results demonstrate that the flipped practical is effective across levels of education: elementary, secondary, and tertiary education. In addition, it does much more than just enhancing conceptual understanding of science, but it also develops higher-order thinking and reasoning abilities (Semab & Nauren, 2022).

Table 5: Results of Post Hoc Analysis of Variance

Dependent Variable	Experimentation Methods	Pairs of Methods	Mean Difference	Sig
RRAT	Demonstration	Open Inquiry	2.7641	.314
		Flipped practical	-4.0907	.075
	Open Inquiry	Demonstration	-2.7641	.314
		Flipped practical	-6.8549*	.<001
	Flipped practical	Demontration	4.0907	.075
		Open Inquiry	6.8549*	<.001
ICUR	Demonstration	Open Inquiry	-1.2678	.814
		Flipped practical	-3.4722	.206
	Open Inquiry	Demonstration	1.2678	.814
		Flipped practical	-2.2044	.534
	Flipped practical	Demonstration	3.4722	.206
		Open Inquiry	2.2044	.534

The intellectual curiosity scores did not discriminate between the experimentation approaches although there is evidence of increased intellectual curiosity. This implies that students in their respective groups were almost equally excited and curious about whatever type of practicals they were exposed to, especially given that there was no significant difference in groups' pretest mean scores. Experimentation is not a common practice in the schools; thus, the students may have been so excited about the experiments or practicals in their respective groups to an extent that they were not keen about the existence of other forms that experimentation could take. Although there was no significant difference in intellectual curiosity across the groups, the results show that the flipped practical approach influenced intellectual curiosity the most, followed by the open inquiry approach. This means that traditional demonstration alone may not meaningfully enhance learners' intellectual curiosity.

CONCLUSION

This study investigated the efficacy of three modes of chemistry practicals: traditional demonstration, open inquiry, and flipped practical, to inform policy reforms on appropriate strategies that maximize learning outcomes in Liberian classrooms and science classrooms elsewhere. While each of the three methods demonstrated some improvement in achievement scores, this study has demonstrated that the flipped practical is appropriate in enhancing conceptual understanding of chemistry. The combined effects of the use of self-regulated learning in multimedia, and the slow-paced guided-inquiry classroom activities may have put the flipped practical in the lead. Although each of the approaches, flipped practical, open inquiry, and demonstration, influenced intellectual curiosity, there is no meaningful difference in the extent to which they separately influenced curiosity. There are several implications for educational reforms as follows: the use of multimedia embedded science experiments, since it arouses learners' curiosity. Teacher training programs should incorporate modules on the use of multimedia in the classroom. The use of low-cost multi media should be considered, with routine monitoring of the intervention and evaluation of the effects thereof. Further research should focus on a combination of innovative strategies, including video-based teaching, peer-teaching strategies, virtual labs, and cooperative engagements. Also, a qualitative or mixed-methods approach may likely provide valuable insights.

APPENDIX A: ACTIVITIES FOR THE OPEN - INQUIRY CHEMISTRY PRACTICALS

Activity 1: The effect of particle size of a solid reactant on the rate of reaction

Students are provided with the following

A. Calcium carbonate available in flakes, grains and powdered

B. 6 test tubes

C. 1 Wash bottle containing water

D. 1 stopwatch

In your respective group and using the materials provided,

1. Design an experimental procedure to determine the effect of particle size of calcium carbonate on the rate of reaction between Calcium carbonate and dilute hydrochloric acid.

2. Carry out the investigation, make keen observations and record your observations on a sheet. Data should include

a. Date

b. Names of participants

c. The mass of calcium carbonate (5g)

d. time taken for bubbles to disappear (in seconds)

3. Note your observation

4. What is the practical everyday application of this investigation?

Activity 2: The effect of temperature on the rate of a reaction rate

Students are provided with the following

A. Magnesium pellet

B. 0.1M hydrochloric acid

C. 1 thermometer

D. 3 beakers holding water at 3 different temperatures

E. 3 test tubes

In your respective group and using the materials provided,

1. Design an experimental procedure to determine the effect of temperature on the rate of chemical reaction between Magnesium metal and 0.1M dilute hydrochloric acid

2. Carry out the investigation, make keen observations and record your observations on a sheet. Data should include

a. Date

b. Names of participants

c. the temperature of the water in the beakers just before pouring it.

d. time taken for the reaction to come to an end.

3. Note your observation

4. What is the practical everyday application of this investigation?

Activity 3: The effects of concentration on the rate of a reaction

In your respective group and using the materials provided,

A. Pellets of magnesium

B. 0.1M, 0.3M, 0.5M solutions of hydrochloric acid

C. 6 test tubes

D. 3 test tube holders

1. Design an experimental procedure to determine the effect of concentration on the rate of the reaction between magnesium and hydrochloric acid

2. Carry out the investigation, make keen observations and record your observations on the activity sheet. Data should include responses to the following;

a. Date

b. Names of participants

c. Time taken for the reaction to come to an end with 0.1M

d. Time taken for the reaction to come to n end with the 0.3M

e. Time taken for the reaction to come an end with the 0.5M

3. Note your observation

4. What is the practical everyday application of this investigation?

Title of Activity 4: Determining the effect of catalysts on the rate of a reaction

In your respective group and using the materials provided,

A. Manganese dioxide (catalyst)

B. Hydrogen peroxide

C. 3 test tubes

D. 3 test tube holders

2. Design an experimental procedure to determine the effect of catalyst on the rate of decomposition of hydrogen peroxide

3. Carry out the investigation, make keen observations and record your observations on the activity sheet. Data should include responses to the following;

a. Date

b. Names of participants

c. Time taken for the reaction to come to completion when a catalyst is used

d. Time taken for the reaction to come to completion when no catalyst is used

e. Note your observation

3. What is the practical everyday application of this investigation?

Activity 5: Plotting graphs of reaction concentration versus time

In your respective group and using the materials provided,

A. Graph sheets

B. One- foot transparent ruler

C. Pencil

D. eraser

1. Design an experimental procedure to determine the effect of concentration on the rate of the reaction between magnesium and hydrochloric acid

2. Plot a graph of concentration of HCl versus time for the following data

Conc(mol/L)	1.5	1.2	1.0	0.8	0.5
Time (s)	0	10	20	30	40

3. Carry out the investigation, make keen observations and record your observations on the activity sheet. Data should include responses to the following;

a. Date

b. Names of participants

c. Determine the slope (units included) of the graph

e. Note your observation

3. What is the practical everyday application of this investigation?

Activity 5: Plotting graphs of reaction concentration versus time

In your respective group and using the materials provided,

A. Graph sheets

B. One- foot transparent ruler

C. Pencil

D. eraser

4. Plot a graph of concentration of HCl versus time for the following data

Conc(mol/L)	1.5	1.2	1.0	0.8	0.5
Time (s)	0	10	20	30	40

5. Carry out the investigation, make keen observations and record your observations on the activity sheet. Data should include responses to the following;

a. Date

b. Names of participants

c. Determine the slope (units included) of the graph

e. Note your observation

3. What did you learn from this practice work?

Activity 6: Plotting a graph of catalyst concentration versus time in a reaction

In your respective group and using the materials provided,

A. Graph sheets

B. One- foot transparent ruler

C. Pencil

D. eraser

6. Plot a graph of concentration of manganese dioxide(as catalyst) versus time for the following data

Amount (g)	0.1	0.2	0.3	0.4	0.5
Time (s)	10	7.0	5.0	2.0	1.0

Make keen observations and record your observations on the activity sheet. Data should include responses to the following;

a. Date

b. Names of participants

c. Determine the slope (units included) of the graph

e. Note your observation

3. What is the practical everyday application of this investigation?

APPENDIX B: THE REACTION RATES ACHIEVEMENT TEST (RRAT)

1. What is the primary goal when investigating the rate of a gas-releasing reaction?

A. To determine the chemical formula of the gas produced.

B. To measure the speed of the reaction by tracking the amount of gas released over time.

C. To find the total mass of the reactants consumed.

D. To identify the product that is a gas.

2. Which of the following is NOT a common method for collecting and measuring the volume of a gas released in a reaction?

A. gas syringes.

B. gas jar with water displacement.

C. balance to measure the loss of mass.

D. gas collection tube inverted over water.

3. To measure the rate of gas production, which quantity must be measured along with time?

A. Temperature of the reaction.

B. Volume of the gas produced.

C. Concentration of the acid.

D. Surface area of the solid reactant.

4. A steeper slope on a graph of volume of gas vs. time indicates:

A. The reaction is slowing down.

B. The reaction is occurring at a faster rate.

C. The reaction has stopped.

D. More reactants are being used.

5. Which factor will DECREASE the rate of reaction if you are reacting calcium carbonate (marble chips) with hydrochloric acid?

A. Increasing the temperature.

B. Using larger marble chips.

C. Decreasing the concentration of the hydrochloric acid.

D. Adding a catalyst.

6. Which piece of equipment is NOT required for measuring the volume of carbon dioxide produced from the reaction of marble chips and dilute hydrochloric acid?

A. Gas syringe.

B. Stopclock.

C. Thermometer.

D. Balance.

7. If two experiments are conducted with different particle sizes of zinc reacting with the same volume of dilute sulfuric acid, and one shows a faster gas evolution rate, what is the likely difference?

A. The temperature was higher for the slower reaction.

B. The acid concentration was lower for the faster reaction.

C. Powdered zinc was used in the faster reaction.

D. The mass of the zinc used was greater in the faster reaction.

8. What does the "activation energy" represent in relation to reaction rate?

A. The total energy released by the reaction.

B. The minimum energy required for a reaction to occur.

C. The energy required to heat the reactants.

D. The energy released by the products.

9. Why does increasing the temperature increase the rate of gas release?

A. It reduces the activation energy.

B. It makes the gas molecules more dense.

C. It increases the frequency of effective collisions between particles.

D. It increases the volume of the container.

10. When investigating the rate at which a gas is released, what are we essentially measuring?

A. The changes in the number of reactant particles per unit time.

B. The rate of consumption of reactants.

C. The speed of the reaction.

D. The enthalpy changes of the reaction.

11. Which of the following methods is most suitable for investigating the rate at which a gas is released from a reaction?

A. Measuring the change in mass of the reactants over time.

B. Measuring the change in temperature of the reaction mixture over time.

C. Measuring the volume of gas collected over time.

D. Measuring the change in pH of the solution over time.

12. In an experiment investigating the rate of gas release, what piece of equipment is typically used to collect and measure the volume of gas produced?

A. Beaker.

B. Measuring cylinder.

C. Gas syringe.

D. Conical flask.

13. The rate of reaction is defined as the change in concentration of a reactant or product per unit time. When measuring the rate of gas release, what quantity is typically measured to determine the rate?

A. Mass of gas produced per second.

B. Volume of gas produced per second.

C. Temperature change per second.

D. Pressure change per second.

14. Which factor would generally lead to an increase in the rate of gas release in a chemical reaction?

A. Decreasing the temperature.

B. Decreasing the concentration of reactants.

C. Increasing the surface area of solid reactants.

D. Removing a catalyst.

15. When plotting a graph of volume of gas produced against time, what does a steeper gradient indicate?

A. A slower rate of reaction.

B. A faster rate of reaction.

C. The reaction has stopped.

D. The reaction is at equilibrium.

16. Consider the reaction between calcium carbonate and hydrochloric acid, which produces carbon dioxide gas. If the concentration of hydrochloric acid is increased, what effect would this have on the rate of gas release?

A. The rate would decrease.

B. The rate would remain unchanged.

C. The rate would increase.

D. The reaction would stop.

17. Why does increasing the temperature generally increase the rate of gas release in a reaction?

A. It decreases the kinetic energy of reactant particles.

B. It increases the activation energy of the reaction.

C. It increases the frequency of effective collisions between reactant particles.

D. It decreases the surface area of the reactants.

18. A catalyst is added to a reaction that produces a gas. What is the primary effect of the catalyst on the rate of gas release?

A. It increases the activation energy.

B. It decreases the total amount of gas produced.

C. It provides an alternative reaction pathway with a lower activation energy.

D. It changes the equilibrium position of the reaction.

19. In an experiment measuring gas release, if the reaction is complete, what would be observed on a graph of volume of gas produced versus time?

A. The graph would show a continuous increase in volume.

B. The graph would show a continuous decrease in volume.

C. The graph would become horizontal, indicating no further gas production.

D. The graph would show oscillations in volume.

20. Which of the following statements about the investigation of gas release rate is incorrect?

A. A stopclock is essential for measuring time intervals.

B. The experiment should be conducted in a well-ventilated area if toxic gases are produced.

C. The initial rate of reaction is often determined from the steepest part of the volume-time graph.

D. The total volume of gas produced is directly proportional to the rate of reaction throughout the entire reaction.

21. How does an increase in temperature affect the rate of a chemical reaction?

A. It decreases the rate of reaction.

B. It increases the rate of reaction.

C. It has no effect on the rate of reaction.

D. It can either increase or decrease the rate depending on the reaction.

22. What happens to reactant molecules when the temperature of a reaction system increases?

A. Their kinetic energy decreases.

B. Their average speed decreases.

C. Their average kinetic energy increases.

D. Their activation energy increases.

23. A higher temperature leads to more frequent collisions between reactant particles. What is the primary reason for this?

A. Particles have less space between them.

B. Particles are moving at higher speeds.

C. The activation energy is lower.

D. More particles are in the gaseous state.

24. Why do more molecules react at higher temperatures, even if the activation energy is constant?

A. There are more particles available for reaction.

B. A larger proportion of molecules possess energy greater than the activation energy.

C. The catalyst works more effectively at higher temperatures.

D. The reactant concentration becomes higher.

25. Which statement correctly describes the effect of temperature on the rate of reaction based on collision theory?

A. Higher temperatures lead to fewer collisions, but these collisions are more energetic.

B. Higher temperatures lead to more frequent and more energetic collisions.

C. Higher temperatures decrease the frequency of collisions and their energy.

D. Higher temperatures increase the frequency of collisions, but they are less energetic.

APPENDIX C: STUDENTS' INTELLECTUAL CURIOSITY QUESTIONNAIRE

S/n	Statement	SD	D	U	D	SA
1	I pay attention when the teacher explains the material					
2	I pay attention to other students who express opinions in group discussions					
3	I pay attention to other students who make presentations in front of the class					
4	I pay attention to each assignment given from the teacher					
5	I record any material given by the teacher					
6	I record any new information I get from friends					
7	I have complete notebooks on the subject matter					
8	I record information from the school noticeboard					
9	I show an effort to understand the subject matter by asking the teacher					
10	I ask questions when discovering new terms from media (print, electronic and social)					
11	I ask questions for each group discussion activity					
12	I asks other students if they hear something they have not known before					
13	I compare the new information obtained with previously known information					
14	I use various sources (books etc.) to understand the subject matter					
15	I compare teachers' opinions with other teachers about a topic					
16	I compare students' opinions with other students about a topic					

REFERENCES

Aktamış, H., Hiğde, E. & Özden, B. (2016). Effects of the Inquiry-Based Learning control, academic engagement and integrated process skills achievement. Journal of Research in Science Teaching, 19, 13-12.

Amineh, R. J., & Asl, H. D. (2015). Review of Constructivism and Social Constructivism. Journal of Social Sciences, Literature and Languages, 1(1), 9-16. http://www.jnasci.

Bathate, M.E., Schunn, C.D. and Correnti, R. (2014), Children's Motivation Toward Science Across Contexts, Manner of Interaction, and Topic. Sci. Ed., 98: 189-215. https://doi.org/10.1002/sce.21095

Abaka, B.O., Abah, J.A., & Agbo-Egwu, A.O. (2018). Science Curiosity as a Correlate of Academic Performance in Mathematics Education: Insights from Nigerian Higher Education. African Journal of Teacher Education 7(1) 36-52. https://doi.org/10.21083/ajote.v7i1.3904

Bicer, A., & Lee, Y. (2019). Effect of STEM PBL Embedded Informal Learning on Student Interest in STEM Majors and Careers. Journal of Mathematics Education, 12(1)57-73.

Bolte, E., & Diehl, J. (2013). Measurement Tools and Target Symptoms/Skills Used to Assess Treatment Response for Individuals with Autism Spectrum Disorder. Journal of autism and developmental disorders. 43. https://doi.org/10.1007/s10803-013-1798-7

Brown, T.L., Lemay, H.E., Bursten, B.E., Murphy, C.J., Woodward, P.M., (2012). Chemistry: The central science. New York: Pearson.

Bunterm, T., Lee, K., Kong, J. N., Srikoon, S., Vangpoomyai, P., Rattanavongsa, J.,& Rachahoon, G. (2014). Do different levels of inquiry lead to different learning outcomes? A comparison between guided and structured inquiry. International Journal of Science Education,36(12), 1937-1959. https://doi.org/10.1080/09500693.2014.886347

Cao, D., Xu, S. C., & Hu, T. T. (2022). Analysis and enlightenment of British junior high school biology textbook column. Biology Teaching, 47(9), 91-92.

Chan, M., Pan, A., Zhao, A., & Zhao, E. (2015). Enhancing Science Education in Liberia: A Trip to Liberia, Summer 2015. New York: I-HELP Liberia. Retrieved on 11th November, 2020 from www.ihelpliberia.orgChrappán, M., Bencze, R.(2017). Transition of teacher in-service trainings and research teacher ambitions in Hungary. In: ATEE Annual Conference "Transitions in teacher education and professional identities" : Proceedings, ATEE And CIEd Institute of Education ; Braga : University of Minho, Brussels, 319-327,. ISBN: 9789081563987

Cohen, J. (1988). Set correlation and contingency tables. Applied Psychological Measurement, 12(4), 425-434. https://doi.org/10.1177/014662168801200410

Fletcher, G. & Griffiths, M, (2020). Digital transformation during lockdown, International Journal of Information Management, 55(C). https://doi.org/10.1016/j.ijinfomgt.2020.102185

Frankael et al, (2012). Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2012). How to Design and Evaluate Research in Education (8th ed.). New York: McGraw-Hill.

Furtak, E. M., Seidel, T., Iverson, H., & Briggs, D. C. (2012). Experimental and quasi-experimental studies of inquiry-based science teaching: A meta-analysis. Review of educational research, 82(3), 300-329. https://doi.org/10.3102/0034654312457206

Ganyaupfu, E.M. (2013). Teaching Methods and Students' Academic Performance. International Journal of Humanities and Social Science Invention,2(9),29-35.Retrieved from http://www.ijhssi.org/papers/v2(9)/Version-2/

Gelgoot, E. S., Bulakowski, P. F., & Worrell, F. C. (2020). Flipping a classroom for academically talented students. Journal of Advanced Academics, 31(4), 451-469. https://doi.org/10.1177/1932202X20919357

Geetanjali, and Singh, R. (2023). Chemistry. A textbook for grade eleven. Monrovia: Ministry of Education, Republic of Liberia.

Gongden, E.J. (2021). The effects of reciprocal peer tutoring on chemistry students' achievement and retention in chemical kinetics in Jos Metropolis, Nigeria. Journal of Education and Practice, 12(24).

Gruber, M. J., & Ranganath, C. (2019). How curiosity enhances hippocampus-dependent memory: The prediction, appraisal, curiosity, and exploration (PACE) framework. Trends in Cognitive Sciences, 23(12), 1014-1025. https://doi.org/10.1016/j.tics.2019.10.003

Gruber, M.J., Gelman, B.D., Ranganath, C (2014). States of Curiosity Modulate Hippocampus-Dependent Learning via the Dopaminergic Circuit, Neuron, 84(2) ,486-496,ISSN 0896-6273. https://doi.org/10.1016/j.neuron.2014.08.060

Gurning, B., & Siregar, A. 2017. "The effect of teaching strategies and curiosity on students achievement in reading comprehension," English Language Teaching, Canadian Center of Science and Education, 10(11), 191-191, November. RePEc:ibn:eltjnl:v:10:y:2017:I:11:p:191 https://doi.org/10.5539/elt.v10n11p191

Halim, S., Wahid, R., & Halim, T. (2018). Classroom observation-A powerful tool for continuous professional development. International Journal on Language, Research and Education Studies,2(2), 162-168. https://doi.org/10.30575/2017/IJLRES-2018050801

Herwin, & Nurhayati, R. (2021). Measuring students' curiosity character using confirmatory factor analysis. European Journal of Educational Research, 10(2), 773-783. https://doi.org/10.12973/eu-jer.10.2.773

Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. Educational and Psychological Measurement, 607-610. https://doi.org/10.1177/001316447003000308

Kurnianto, B., Wiyanto, W., & Haryani, S. (2019). Critical Thinking Skills and Learning Outcomes by Improving Motivation in the Model of Flipped Classroom. Journal of Primary Education, 8(6), 282-291.

Love, B., Hodge, A., Grandgenett, N., & Swift, A. W. (2014). Student learning and perceptions in a flipped Linear Algebra course. International Journal of Mathematical Education in Science and Technology, 45(3), 317-324. https://doi.org/10.1080/0020739X.2013.822582

Khan, M., Hussain, S., Ali, R., Majoka, M., & Ramzan, M. (2011). Effect of inquiry method on achievement of students in chemistry at secondary level. International Journal of Academic Research. 3. 955-959. https://www.researchgate.net/publication/298817469

Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. Educational and Psychological Measurement, 30(3), 607-610. https://doi.org/10.1177/001316447003000308

Kurnianto, B., Wiyanto, W., & Haryani, S. (2019). Critical Thinking Skills and Learning Outcomes by Improving Motivation in the Model of Flipped Classroom. Journal of Primary Education, 8(6), 282-291.

Murat, M., & Cam, A. (2021). Flipped Classroom on Fifth Grades' 21st Century Skills and Scientific Epistemological Beliefs. International Journal of Technology in Education, 4(4), 752-771. https://doi.org/10.46328/ijte.94

Nicol (2021). An Overview of Inquiry-based science instruction amid challenges. EURASIA Journal of Mathematics, Science and Technology Education, 2021, 17(12), em2042. https://doi.org/10.29333/ejmste/11350

Pallant, J. (2016). SPSS survival manual: A step by step guide to data analysis using SPSS version 18 (6th ed.). Maidenhead, Berkshire: Open University

Press.Potvin, P., & Hasni, A. (2014). Interest, motivation and attitude towards science and technology at K-12 levels: a systematic review of 12 years of educational research. Studies in Science Education, 50(1), 85-129. https://doi.org/10.1080/03057267.2014.881626

Said, Z., Summers, R., Abd-El-Khalick, F., & Wang, S. (2016). Attitudes toward science among grades 3 through 12 Arab students in Qatar: findings from a cross-sectional national study, International Journal of Science Education. https://doi.org/10.1080/09500693.2016.1156184

Semab, T. & Naureen, S(2022). Effects of flipped classroom model on academic achievement of students at elementary level. Pakistan J. Soc. Res. 4(1), 393-401 ISSN 2710-3129 (P) 2710-3137 (O). https://doi.org/10.52567/pjsr.v4i1.663

Sesen & Tarhan, 2013; Sesen, B. A., & Tarhan, L. (2013). Inquiry-Based Laboratory Activities in Electrochemistry: High School Students' Achievements and Attitudes. Res Sci Educ, 43, 413-435. https://doi.org/10.1007/s11165-011-9275-9

Sherbino, J (2013). The reverse classroom: lectures on your own and homework with faculty. Canadian Association of Emergency Physicians 15(3): 179-181. https://doi.org/10.2310/8000.2013.130996

Tan, A. L., Poon, C. L., & Lim, S. S. 2014. Inquiry into the Singapore Science Classroom. Singapore: Springer. https://doi.org/10.1007/978-981-4585-78-1

Tessa, B., Deon, F., Gayle, M., Ezequiel, M., Christophe, R.,Brian, S., Jakob, S.,Waly, W. 2017. What Do Teachers Know and Do? Does It Matter?: Evidence from Primary Schools in Africa. Policy Research Working Paper;No. 7956. © World Bank. http://hdl.handle.net/10986

Kadek, D.,Burmansah, A.,Tupari, T., Poniman, P(2020). How is the student emotional intelligence enhanced by developing mindfulness approach in the higher education school?Lighthouse international conference proceeding 2023, 1, 251 - 258

UNESCO (2015). Global Education Monitoring Report. https://en.unesco.org/gem-report/taxonomy/term/199. Retrieved September 6,2024

WAEC. (2020). Results for the Liberia Junior and senior high school examinations. Monrovia: WAEC.

WAEC(2021). Results for the Liberia Junior and senior high school examinations. Monrovia: WAEC.

WAEC(2022). Results for the Liberia Junior and senior high school examinations. Monrovia: WAEC.

WAEC(2023).Results for the Liberia Junior and senior high school examinations. Monrovia: WAEC.

Wei, X., Cheng, I., Chen, N. S., Yang, X., Liu, Y., Dong, Y., & Zhai, X. (2020). Effect of the flipped classroom on the mathematics performance of middle school students. Educational Technology Research and Development, 68(3), 1461-1484. https://doi.org/10.1007/s11423-020-09752-x

Yıldırım, A. & Berberoglu, G. (2012). Rehberli Sorgulama Deneylerinin BilimselSüreç Becerilerinin Kazandırılmasına, Başarıya ve Kavramsal Değişime Etkisi. Unpublished master thesis, Middle East Technical University, Ankara.

https://doi.org/10.65638/2978-5634.2025.01.12