Effect of Guided Inquiry-Based Experiments on Students' Acquisition of Physics Practical Skills in Ordinary Level Secondary Schools in Tanzania

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Abstract

This study investigated the effect of Guided Inquiry-Based Experiments (GIBE) on students' acquisition of Physics practical skills in Ordinary-level secondary schools in Tanzania. The study applied a quasi-experimental design and involved 82 participants. Data were collected by using the observation rubric and analysed through descriptive and inferential statistics techniques. Results indicate a significant difference in the mean scores with a large effect size for the acquisition of Physics practical skills in the domain of design, execution, analysis and evaluation between students in the experimental school and the control school. These findings suggest that GIBE is superior to Traditional-Based Experiments (TBE) in enhancing students' acquisition of practical skills in Physics. Therefore, Physics teachers should be encouraged to integrate laboratory practical activities in the form of GIBE in Physics lessons to enhance students' acquisition of practical skills which are essential attributes for effective learning of Physics.

Keywords: *acquisition, guided inquiry-based experiments, practical skills, physics learning*

DOI: *https://dx.doi.org/10.56279/ped.v42i2.special.7*

Introduction

The teaching and learning of Physics in secondary schools encompass both theoretical instruction and laboratory experiments, which are complementary in facilitating students' acquisition of knowledge and practical skills (Sudarmani et al., 2018). The science curriculum emphasizes laboratory experiments to foster students' inquiry skills and hands-on competencies, thereby enhancing their learning and achievement in science subjects (Ministry of Education and Vocational Training [MoEVT], 2007). However, in Tanzanian secondary schools, the teaching of science subjects, including Physics, remains largely reliant on the Traditional-Based Experiments

(TBE) approach (Mkimbili, 2018). During Physics practical sessions, teachers typically design step-by-step activities that require students to verify established facts, laws, and principles, demonstrate learned concepts, or prepare for practical exams, with minimal focus on fostering independent practical skills and knowledge acquisition (Mkimbili, 2018; Mkimbili et al., 2017). This reliance on TBE constrains students' ability to develop essential practical skills necessary for meaningful learning in Physics. Consequently, students have consistently underperformed in the subject due to their limited proficiency in conducting Physics experiments during practical examinations (National Examination Council of Tanzania [NECTA], 2022). An analysis of NECTA reports on students' performance in the Certificate of Secondary Education Examination (CSEE) indicates that poor performance in Physics is largely attributed to students' inability to recall and apply the requisite practical skills for conducting experiments (NECTA, 2020).

In the 21st century, there is emerging interest in using student-driven inquiry-based laboratory experiments that allow students to take ownership of their experimental work when learning physics (Cai et al., 2021). The science curriculum reforms that took place in Asian, American and African countries called for a shift from traditional-based experiments to more student-centered inquiry-based experiments (Babalola et al., 2020; Gudyanga & Jita, 2019). The use of inquiry-based laboratory activities is encouraged in science curriculum reforms to give students greater autonomy in deciding what and how physical phenomena should be investigated rather than simply following instructions written in a laboratory guide (Wilcox & Lewandowski, 2016).

Levels of inquiry-based experiments

Inquiry-based experiments are designed in four levels, ranging from highly structured to highly unstructured based on the degree of guidance that teachers offer to students (Zion & Sadeh, 2007). These levels of inquiry are confirmatory experiments, structured experiments, guided inquiry-based experiments and open inquiry-based experiments (Zion & Sadeh, 2007). They were established to guide teachers on the degree of assistance offered to students during the process of teaching Physics through laboratory work (Figure 1).

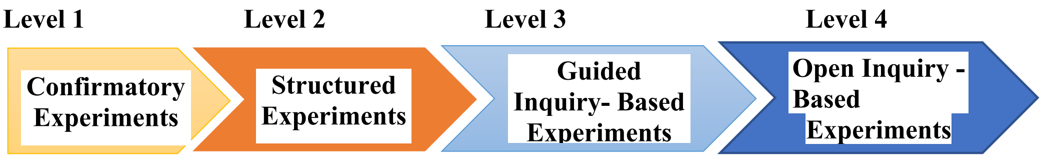

Figure 1. *Continuum of inquiry-based experiments*

The confirmatory and structured experiments represent lower inquiry levels where the teacher structures both the problem and procedures of carrying out the experiment so that students confirm a learned concept, theory, principle or scientific law after the content has been taught (Baloyi, 2017; Ural, 2016). These forms of experiments are neither true inquiry nor an effective way of developing practical skills and scientific inquiry among students (Fitzgerald et al., 2019). Thus, both confirmatory and structured experiments are regarded as TBEs. The third level of inquiry is GIBE, in which students actively engage in authentic learning activities to accomplish the assigned tasks under their teacher's guidance (Baloyi, 2017). The fourth level is an open inquiry-based experiment which represents the highest level of inquiry, where students formulate their own questions and design their own experimental methods to address the problem. Open inquiry-based experiments are very difficult to translate into teaching activities because they are highly unstructured, making it difficult for students to formulate their own problems and experimental procedures (Kinyota, 2020; Baloyi, 2017; Ural, 2016). Research shows that secondary school students can learn Physics better through GIBE than through traditional or other forms of experiments (Chatterjee et al., 2009).

Traditional-based experiments

TBEs are a form of laboratory work introduced in a step-by-step manner for students to complete the experimental task given in the worksheet (Wieman, 2015). In TBE, students are required to follow the prescribed step-by-step instructions to accomplish the assigned practical task (Chung et al., 2010). The main focus of TBEs is to teach students how to use equipment and take measurements to verify known theories, principles, facts or concepts. As a result, students can miss the potential opportunity to experience the nonlinear and complex nature of science (Kalender et al., 2021). In TBE students are told what to find, acquainted with the procedures, record their readings in tables, given the formulas needed, and are even aware of the expected answers or conclusions (Gangoli & Gurumurthy, 2007). As a result, TBE may lead to students memorizing facts and procedures instead of making a connection between the experiment and the underlying scientific concepts or ideas (Abrahams & Millar, 2008).

Guided inquiry-based experiments (GIBEs)

In GIBEs, students are provided with fewer directions but they are assigned more responsibilities to determine procedural strategies, which encourages them to make more use of practical skills (Shi et al., 2020). In GIBE, the teachers provide students with guidance in the form of leading questions to actively engage them in determining the concept through experimental inquiry activities (Maknun, 2020). One advantage of GIBE is that the leading questions are less likely to lead to frustration and anxiety among students when conducting experiments (Furtak et al., 2012). Moreover, in the GIBE approach students have a chance to ask questions, develop hypotheses, decide on the experiment design in groups, and organize roles in their experiment groups (Aydın, 2016). These GIBE practical activities can enhance students' acquisition of practical skills, hence improving their learning and achievement in Physics.

Practical skills in Physics

Process skills, inquiry skills, manipulative skills, and procedural understanding are the key practical skills that Physics students in secondary schools are expected to acquire (Liew et al., 2019; Hastuti et al., 2018; National Research Council, 2012; Akinbobola & Afolabi, 2010). These important practical skills are grouped into four domains as per the Hypothetical-Deductive Model, namely design, execution, analysis and evaluation (Liew et al., 2019). The domain of design includes practical skills such as identifying variables, choosing suitable apparatuses and designing an experimental set-up. Skills that fall under the domain of execution include setting up the apparatus, checking and using instruments with correct techniques, manipulating variables and recording data. Moreover, the domain of analysis encompasses skills related to data handling, which include performing correct calculations, analysing data to identify relationships, and making suitable deductions. The domain of evaluation encompasses skills related to students' ability to evaluate experimental results and make judgement, which include drawing conclusions judging the accuracy of results, identifying sources of errors and weaknesses, and suggesting methods to improve the experimental results (Liew et al., 2019, p. 5).

Acquisition of practical skills in Physics

The active learning activities in GIBE help students to develop their cognitive processes and practical skills in Physics unlike the step-by-step learning activities in TBE which do not allow students to further explore the experiments (Chung et al., 2010). For example, one study conducted in Indonesia revealed that Junior high school students taught through experiments done by using a guided inquiry-based approach had higher learning achievement in practical skills compared to the students who were in the control class where they were taught by using the scientific approach (Hastuti et al., 2018). Similarly, the experiment-based guided inquiry learning (EBGIL) approach was found to be superior to the experimental-based problem learning (EBPL) approach in enhancing students' acquisition of practical skills (Halim et al., 2021). These findings imply that laboratory activities in the form of the GIBE approach can be superior to other direct approaches such as the TBE approach in supporting the development of practical skills among students.

Even though some empirical studies acknowledge GIBE as a promising learning approach that can enhance students' acquisition of practical skills in Physics, there is still little evidence in the literature on its efficacy in O-level secondary schools in Tanzania. A study by Kinyota (2020) examined the extent to which inquiry-based science teaching and the nature of science are featured in secondary school curriculum documents for science subjects. Another study by Mkimbili et al. (2017) investigated the extent to which science teachers practice inquiry-based science teaching. Yet, little is known about how GIBE can enhance students' acquisition of practical skills to improve their learning achievement in Physics in Ordinary level secondary schools in Tanzania. These concerns call for the need to investigate the effect of GIBE on students' acquisition of Physics practical skills in the selected Ordinary level secondary schools in Tanzania.

Research question

To what extent do the guided inquiry-based experiments enhance students' acquisition of Physics practical skills in Ordinary level secondary schools?

Null hypotheses

The study tested four null hypotheses at a significant level of $p < .05$, which are as follows:

H_{01}: There is no significant effect of guided inquiry-based experiments on enhancing students' ability to design experiments in Physics.

H_{02}: There is no significant effect of guided inquiry-based experiments on developing students' ability to perform experiments in Physics.

H_{03}: The guided inquiry-based experiments have no significant effect in enhancing students' ability to analyse data in Physics experiments.

H_{04}: The guided inquiry-based experiments have no significant effect on developing students' ability to evaluate experimental results in Physics.

Theoretical Framework

The study was guided by constructivist learning theory based on the ideas of John Dewey. Dewey's constructivism holds the idea that in science learning comes out of authentic laboratory experiences such as observing phenomena, investigating and solving problems (Fan, 2015). The theory implies that the teaching and learning process should provide learners with an opportunity to explore their environments. The constructivist theory calls for the kind of learning that is hands-on, minds-on and authentic. The GIBE approach is situated within constructivist learning theory in which the learner is a creator of understanding under the guidance of the teacher as a facilitator. With Dewey's constructivist theory, the teaching and learning process need to be designed in a way that provokes anticipation with evocative materials enabling students to unravel a mystery rather than follow a recipe (Herman & Pinard, 2015). Therefore, with Dewey's constructivism, teachers should play multiple roles such as a facilitator during GIBE laboratory practical sessions to help students acquire practical skills essential for effective Physics learning.

Methodology

Research approach and design

The study employed a quantitative research approach to investigate the effect of GIBE on enhancing students' acquisition of Physics practical skills in the two selected Ordinary level secondary schools from Iringa and Morogoro regions in Tanzania. The quantitative research method enables the researcher to investigate research problems that call for the identification of factors that influence an outcome, the utility of an intervention or understanding the best predictors of outcomes (Cresswell & Cresswell, 2018). Therefore, with the quantitative research approach, we were able to collect quantifiable data from participants who participated in the intervention to attain accurate results needed to understand the effect of GIBE on students' acquisition of Physics practical skills. The study applied a non-equivalent quasi-experimental research design with pre-test and post-test comparison groups to minimize interruptions of students' normal learning settings in the selected schools during the intervention. Students from one demonstration secondary school in the Iringa region participated as an experimental group, and others from another demonstration secondary school in the Morogoro region participated as the control group. The characteristics of students in both schools in terms of prior practical skills and learning environments in terms of availability of Physics teachers and laboratory equipment of their schools were relatively the same.

Participants

A total of 82 Form Three students from two demonstration secondary schools in Iringa and Morogoro participated in the study. These students were taking Physics as a major subject. 49 students from the selected demonstration secondary school in the Iringa region were assigned to the experimental group and the other 33 students from the demonstration school in the Morogoro region to the control group. Among the students in the sample, male students comprised 52.4% while female students comprised 47.6% of the sample size. The two-demonstration secondary schools were purposefully selected to access Form Three students, who had similar characteristics in terms of learning environment and prior skills in doing Physics practical activities.

Instruments

The study applied laboratory worksheets, Physics practical tests and a practical skills observation rubric to collect the data needed to test the null hypotheses. We designed and used the laboratory worksheets to teach Physics practical activities in the form of GIBE for the students in the experimental school. We adopted a 4-D model proposed by Thiagarajan et al. (1974) to guide the process of developing and implementing the laboratory worksheets in the form of GIBE. The 4-D model provided us with coherent procedural specifications and guidelines in four key stages: define, design, develop and disseminate required for developing the laboratory worksheets. In the define stage, we set and defined learning prerequisites, including competencies and concepts. In the design process, we transformed the experiments in the form of TBE from Ordinary level Physics practical manuals in the topics of Light and Current Electricity specified by NECTA (2021) into GIBE format. The learning activities in GIBE were sequenced in five phases of implementation, which are orientation, conceptualization, investigation, conclusion and discussion based on the guidelines of the Inquiry Learning Model established by Pedaste et al. (2015).

In the develop stage, we tested the validity and practicality of the designed lab worksheets. We consulted nine experts in the area of science teaching to validate the lab worksheets in terms of content, relevance, language and graphics, whereby, the computed Aiken's score (V) was 0.81. According to the interpretation guideline by Cahyati and Yohandri (2020), this value was greater than the minimum acceptable value of 0.60 ($V > 0.60$), which means that the designed lab worksheets were valid.

On the other hand, the lab worksheets were piloted to Form Three students (*n* = 12) studying Physics in one of the demonstration schools in the Dar es Salaam region. Thereafter, the lab worksheets were rated by two Physics teachers and the 12 Form three students participated in the pilot study to test their practicality in terms of attractiveness, ease of use, time efficiency, graphics and usefulness. The computed average percentage value was 84.95. According to the interpreting guideline by Ananda and Usmeldi (2023), the computed average percentage value was greater than the minimum acceptable value of 61% indicating that the developed laboratory worksheets in the form of GIBE were practical.

We prepared a Physics practical test to assess students' practical skills in both the experimental school and the control school before and after intervention. The practical test comprised two practical questions: one from the topic of Light and another from the topic of Current Electricity, adapted from the standardised practical questions administered by the NECTA in the years 2014 and 2022 (Figure 2). Also, we adopted the practical observation rubric developed by Liew et al. (2019) to score the practical skills demonstrated by students while performing the Physics practical test. The scoring rubric was used to assess students' practical skills in the four domains: the domain of design, the domain of execution, the domain of analysis and the domain of evaluation (Appendix I). We calculated the content validity index (CVI) of the adapted practical skills observation rubric from the nine ($n = 9$) experts' ratings and its inter-rater reliability/Kappa coefficient (K) for raters in the experimental school and the control school from the raters' scores. The calculated value of CVI was 0.94, greater than the threshold value of 0.74 suggested by Lawshe in Shultz et al. (2014), which implies high validity of the items of the practical skills observation rubric (Liew et al., 2019). In the experimental school (Rater 1 &2), the value of the Kappa coefficient (K) was 0.77 while in the control school (Rater 3 & 4) it was 0.74. The computed values of Kappa coefficients (K) exceeded a minimum acceptable value of 0.70 (K>.70), implying strong agreement between the raters in both the experimental school and the control school.

2. Find a dry cell, resistance box, switch, an ammeter and a set of connecting wires in the laboratory

Then proceed as follows:

(a) Connect the selected electrical components in series, switch must be open. Draw and label clearly your circuit.

(b) Set resistance R= 1Ω, then close the switch. Read and record the ammeter reading, open the switch immediately after taking the readings.

(c) Repeat procedure 2 (b), setting the value of R= 2Ω, 3Ω, 4Ω and 5Ω.

Questions

(i) Tabulate your results including the values of 1/I.

(ii) Plot a graph of R against 1/I.

(iii) From the graph determine the slope and the vertical intercept.

(iv) Use the results obtained in 2 (iii) to determine the internal resistance and e.m.f of the selected dry cell.

(v) State two sources of errors and suggest two precautions to avoid the stated errors in this experiment.

(vi) What is the aim of doing this experiment?

Figure 2: *Sample of practical questions in Physics practical test.*

The implementation of an intervention

In the disseminate stage of the 4-D model, we distributed laboratory worksheets to regular Physics teachers for intervention in the experimental school. Before the intervention, we deliberated on students' informed consent where the selected Form Three students were informed about the study's purpose and the nature of intervention activities and that, their participation was voluntary and they could withdraw from the study at any time. Then they were invited to participate in the study. We assessed the students' prior practical skills in Physics in both the experimental school and the control school. Thereafter, we conducted a two-day training seminar for two regular Physics teachers in the experimental school on how to teach the selected topics using the developed laboratory worksheets with experiments in the form of GIBE. The trained teachers prepared lesson plans with learning activities sequenced in five phases: orientation, conceptualization, investigation, conclusion and discussion (Appendix II) based on the Inquiry-Based Learning Model by Pedaste et al. (2015) for teaching Physics laboratory work in the form of the GIBE.

The intervention began with the orientation phase, in which the teacher and students collaboratively decided the aim of the experiment. In the conceptualization phase, the students asked questions and formulated a problem and hypotheses. In the investigation phase, the students planned the exploration, conducted experiments, and collected and analyzed data to generate answers and explanations to the stated problem/question. Finally, in the discussion phase, the students were encouraged to present and communicate the results of their experiments to others, reflect, evaluate the experimental results, and state how they would apply the generated knowledge in their daily lives. The trained teachers prepared, developed and then taught a total of 10 lessons, each of which took 80 minutes. The intervention was done for six weeks, followed by post-testing.

Contrarily, we consulted two Physics teachers in the control school to teach the same topics to Form Three students by using the TBE approach. No training was offered to these Physics teachers. The teachers planned and taught the lessons using the common lesson plans designed by the MoEVT. The lesson development template had five stages, namely introduction, new knowledge, reinforcement, reflection and consolidation (Appendix III). Like the teachers of the experimental school, these teachers prepared and taught the same number of lessons in 80 minutes by using the laboratory worksheets with exemplary experiments in the form of TBE adopted from NECTA (2021) for six weeks followed by post-testing.

Data collection procedures

The data were collected using adopted practical skills observation rubrics. To achieve data collection with minimal researchers' biases, we conducted a one-day training seminar for four Physics tutors from the Teachers' Colleges in the respective Iringa and Morogoro regions on how to rate students' practical skills using the adopted practical skills observation rubrics. Two Physics tutors from one of the Teachers' College in Iringa region administrating the experimental school as its demonstration school were trained to rate students' practical skills in the experimental school. The other two Physics tutors from Teachers' College in Morogoro region administrating the control school as its demonstration school, received the same training to rate students' practical skills in the control school. The trained tutors used the practical skills observation rubrics to score students' practical skills demonstrated when conducting experiments in Physics practical tests before and after intervention. The study used the same data collection instruments with the same items under the same conditions in pre-testing and post-testing in the experimental and the control school to control instrumentation and selection threats to the validity of research findings.

Data analysis procedures

Descriptive and inferential statistical techniques were used to analyze data collected through practical skills observation rubrics. The descriptive statistics were used to report data analysis in the pre-test and post-test results in terms of normalised gain (<*g*>), means and standard deviations. The normalised gain (<g>) scores were interpreted based on the guideline by Hake (1998), whereby (<g>) ≥ 0.70 = high, 0.70 > (<g>) ≥ 0.30 = moderate and (<g>) < 0.30 = low. In inferential statistics, we performed paired and independent sample t-tests and reported effect size (*Cohen's d*) with the aid of SPSS version 25. The paired sample t-test was performed to understand the effectiveness of GIBE and TBE in the respective experimental and control groups. The independent sample t-test was conducted to assess the differences in post-test mean scores for the acquisition of practical skills between students in the experimental school and control school. The inferential statistics tests were performed at a level of significance of $p < .05$. The values of effect sizes were interpreted based on the guideline proposed by Cohen (1988, p. 22) where Cohen's d = .20 (small effect), d = .50 (medium effect) and d = .80 and above (large effect).

Results and Discussion

Pre-testing results

An independent sample *t*-test was conducted to assess students' prior practical skills in Physics in the experimental school and control school before the intervention, at a level of significance of $p < .05$. The results show that there was no significant difference in the mean scores between students in the experimental school *(M* = 16.20, *SD* = 8.68) and those the control school (*M* = 18.55, *SD* = 4.94), t (80) = – 1.55, p = .125, (two-tailed). Similarly, the series of independent sample *t*-tests that were performed for each domain of practical skills (domain of design, execution, analysis and evaluation) showed no significant difference in the mean scores between the experimental school and the control school. Table 1 presents the inferential statistical results for pre-testing.

Table 1

Pre-test Independent Samples T-tests of Students' Mean Practical skills Scores

Domain	**Experimental School**		**Control School**				
	M	*SD*	*M*	*SD*	*(df)*	*t*	*p*
Design	4.08	2.67	3.91	1.86	80	0.32	.748
Execution	7.69	4.40	9.30	2.83	80	-1.86	.067
Analysis	2.06	1.78	2.61	1.48	80	-1.46	.149
Evaluation	2.37	2.35	2.73	1.99	80	-0.72	.472
Total Mean Scores	16.20	8.68	18.55	4.94	80	-1.55	.125

Key*:* *M* = Mean*,* *SD* = Standard

The results presented in Table 1 indicate that the pre-test mean scores were higher in the control school than in the experimental school for the domain of execution, analysis and evaluation. However, the inferential statistical results show that there were no significant differences in mean scores in the experimental school and the control school. These results suggest that the student's prior practical skills in both schools in all four domains were considered equal before intervention. Hence, we implemented the intervention in these schools with confidence that no automatic bias would occur due to students' differences in prior practical skills.

Domain of design

The domain of design involved the assessment of four practical skills which were related to students' ability to design an experiment. These practical skills included students' ability to identify variables correctly, design functional experimental set-ups, determine suitable ranges for manipulated variables and ability to select suitable intervals for values of manipulated variables. The mean scores and normalised gain (<*g*>) were computed to assess gain in the mean scores in the domains of design after implementation of GIBE in the experimental school, and TBE in the control school. Figure 3 presents the normalised gain scores.

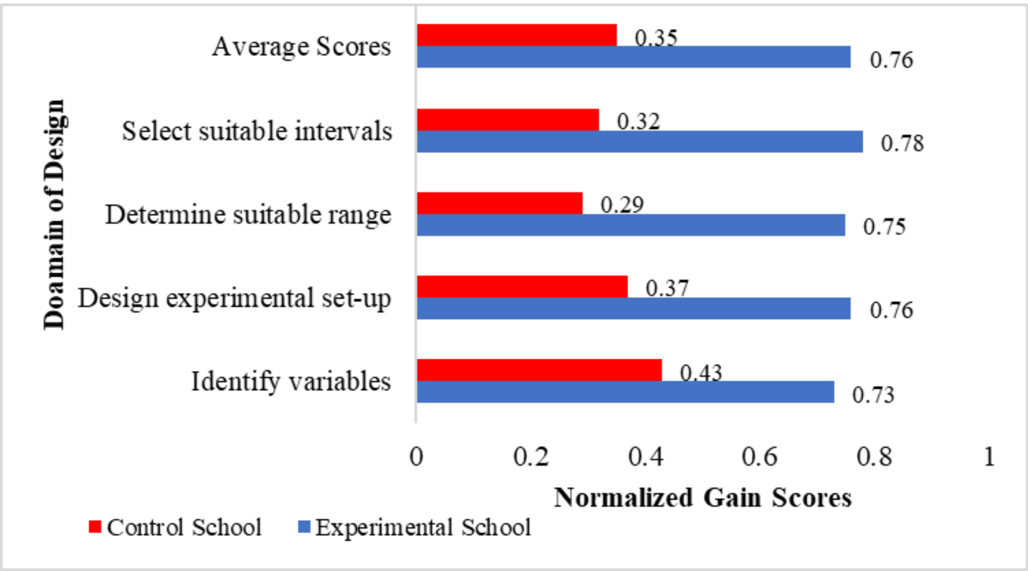

Figure 3: *Normalised gain scores in the experimental school and the control school for domain of design*

The results in Figure 3 show that, the normalised gain *(<g>)* score in the experimental school was highest in developing students' ability to select suitable intervals, followed by the ability to design a functional experimental set-up, determine a suitable range and identify variables correctly. In the control school, students' ability to identify variables correctly had moderate scores followed by the ability to design functional experimental set-up and select suitable intervals. Students in the control school had low normalised gain scores for the ability to determine a suitable range. A paired sample *t*-test was performed to find out if a change in students' mean scores for the acquisition of practical skills in the domain of design from pre-test to post-test in the experimental school and the control school was significant. Table 2 presents the results.

Table 2

Paired Sample T-Test Results for the Domain of Design in The Experimental and the Control School

Schools	**Pre-test**			**Post-test**									
	N	*M*	*SD*	*N*	*M*	*SD*	*(df)*	*t*	*p*	*d*	*MD*	*Lower*	*Upper*
Experimental	49	4.07	2.67	46	10.07	2.73	45	-10.99	.000	3.29	-6.02	-7.12	-4.92
Control	33	3.91	1.86	33	6.76	1.79	32	-7.93	.000	2.79	-2.83	-3.58	-2.12

Key: *p* = Significant level, *t* = t-value, d = Cohen's d and *MD* = Mean difference.

The results in Table 2 indicate that there was a statistically significant increase in mean scores from the pre-test to the post-test in both the experimental school and the control school. GIBE and TBE resulted in a large effect size with Cohen's d values of 3.29 and 2.79 respectively. The independent sample *t*-test was performed to test if the difference in post-test mean scores between the experimental and the control school was statistically significant. Table 3 presents the results.

Table 3

Independent Sample T-test Results for the Domain of Design in the Experimental and the Control School

Experimental School			**Control School**									
N	*M*	*SD*	*N*	*M*	*SD*	*(df)*	*t*	*p*	*d*	*MD*	*Lower*	*Upper*
46	10.07	2.73	33	6.76	1.79	77	6.09	.000	2.67	3.31	2.23	4.39

The results in Table 4 indicate a statistically significant difference in mean scores for students' acquisition of practical skills in the domain of design between the experimental school and the control school. GIBE had a large effect size with Cohen's d value of 2.67. The significant level was 0.000 ($p < .05$), rejecting the first null hypothesis (H_{01}) that, there is no significant effect of guided inquiry-based experiments on enhancing students' ability to design experiments in Physics.

The independent t-test results affirmed that there was a significant difference with a large effect size in the acquisition of practical skills in the domain of design between students in the experimental school and the control school. In the GIBE classroom, the students discussed and agreed on the nature of independent and dependent variables, designed functional experimental set-ups, and determined suitable ranges and intervals of manipulated variables. The practical activities in the investigation of GIBE might have played a fundamental role in enhancing the development of practical skills related to student's ability to design experiments in physics in the experimental school. Unlike the practical activities in TBE where students were required just to follow the prescribed step-by-step procedures while performing the assigned practical tasks.

Similar claims were reported by Juniar et al. (2020) that the use of a guided inquiry model resulted in substantial development of students' ability to design experiments in Chemistry. However, the findings in this study contrast with those by Blumer and Beck (2019) that, the use of laboratory courses with guided inquiry modules did not improve students' scientific reasoning skills and experimental design skills from pre-test to post-test. This is attributed to the fact that, in GIBE practical activities students tend to experience some difficulties in designing reliable experiments to solve the assigned practical tasks. The findings by Sujarittham et al. (2019) revealed that, the use of guided-inquiry laboratory worksheets enhanced only students' ability to identify experimental variables of an investigation because students spent much time designing the experiment by working on answering the guided-inquiry questions and doing the experiments.

Domain of execution

In the domain of execution, eight practical skills related to students' ability to perform an experiment were assessed. They included students' ability to choose suitable apparatus for measurement, check the functionality of instruments, set up functional apparatus, and test-run the experimental set-up. Other skills were the ability to use measuring instruments with the correct techniques, take precautions to improve the accuracy of data collected, record all measurements and ensure safety in the laboratory. The normalised gain ($<g>$) was calculated to assess the gain in the mean scores after GIBE intervention in the experimental school, and TBE in the control school. Figure 4 presents the normalised gain scores.

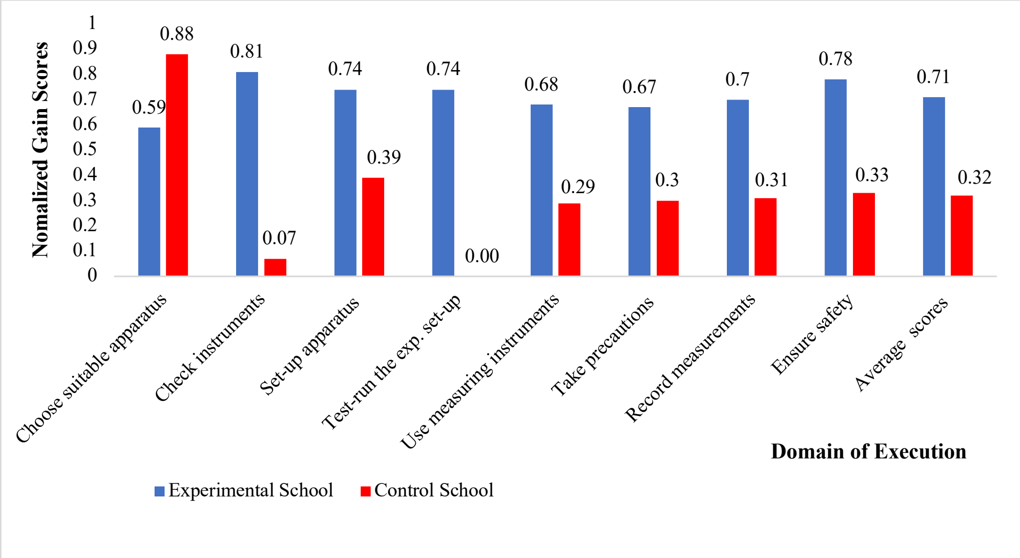

Figure 4: *Normalised gain scores in the experimental school and control school domain of execution*

The results in Figure 4 indicate that students in the experimental school had higher normalised gain *(<g>)* scores than those in the control school for all the assessed practical skills except the ability to choose suitable apparatus. In the control school, the student's ability to test run the experimental set-up had no mean gain. A paired sample *t*-test was performed in both the experimental school and the control school to test if the changes from pre-test to post-test were statistically significant. The results are presented in Table 4.

Table 4

Paired Sample T-test Results for the Domain of Execution in the Experimental and the Control School

Schools	Pre-test			Post-test									
	N	*M*	*SD*	*N*	*M*	*SD*	*(df)*	*t*	*p*	*d*	*MD*	*Lower*	*Upper*
Experimental	49	7.69	4.40	46	19.48	3.75	45	-14.86	.000	4.42	-11.93	-13.55	-10.32
Control	33	9.30	2.83	33	12.85	2.72	32	-5.35	.000	1.88	-3.55	-4.90	-2.19

The results in Table 4 show that, there was a statistically significant increase in mean scores from the pre-test to post-test in the experimental school and the control school. The effect sizes of GIBE and TBE were large with Cohen's d values of 4.42 and 1.88, respectively. The independent sample *t*-test was conducted to test if the difference in post-test mean scores between the experimental school and the control school was statistically significant. Table 5 presents the results.

Table 5

Independent Sample T-test Results for the Domain of Execution in Experimental and Control School

Experimental School			Control School									
N	*M*	*SD*	*N*	*M*	*SD*	*(df)*	*t*	*p*	*d*	*MD*	*Lower*	*Upper*
46	19.48	3.75	33	12.85	2.72	77	8.65	.000	1.96	6.63	5.10	8.16

The results in Table 5 indicated a statistically significant difference in the mean scores for students between the experimental school and the control school. The GIBE had a large effect size with Cohen's d statistic value of 1.96. The significant level was 0.000 (p <.05), rejecting the second null hypothesis (H_{02}) that, there is no significant effect of guided inquiry-based experiments on developing students' ability to perform experiments in Physics.

The findings revealed that students in the experimental school scored higher normalised gain *(<g>)* scores than those in the control school in seven assessed practical skills except the ability to choose suitable apparatus. This observation might be attributed to the nature of practical activities in TBE where students in the control school were directly given the required apparatus unlike in the GIBE approach where students had to select the relevant apparatus themselves. Moreover, the use of the GIBE approach attributed to significantly higher mean scores in the experimental school as compared to those in the control school in enhancing the development of practical skills related to students' ability to perform experiments. This implies that the GIBE practical activities in the investigation phase enabled students to develop the ability to choose, check and use measuring instruments, and do observation to collect the data needed to explain the concepts under investigation. This observation concurs with Hastuti et al. (2018) that, the procedural and manipulative skills which focus on tool operation develop well when students are given an opportunity to practice directly through laboratory experiments under the GIBE approach. Similarly, the use of the guided–inquiry laboratory experiments model in teaching was found to be effective in improving the quality of students' ability to carry out experiments in Chemistry courses (Wahyuni & Analita, 2017). Students are better at using equipment and carrying out practical procedures if they get opportunities to practice how to operate them rather than just being shown how they operate (Millar, 2010).

Domain of analysis

In the domain of analysis, the study assessed three practical skills that covered student's ability in data handling. These included: students' ability to perform correct calculations, analyse data to obtain results/relationships and state the correct relationship/make correct deductions. The normalised gain scores are presented in Figure 5.

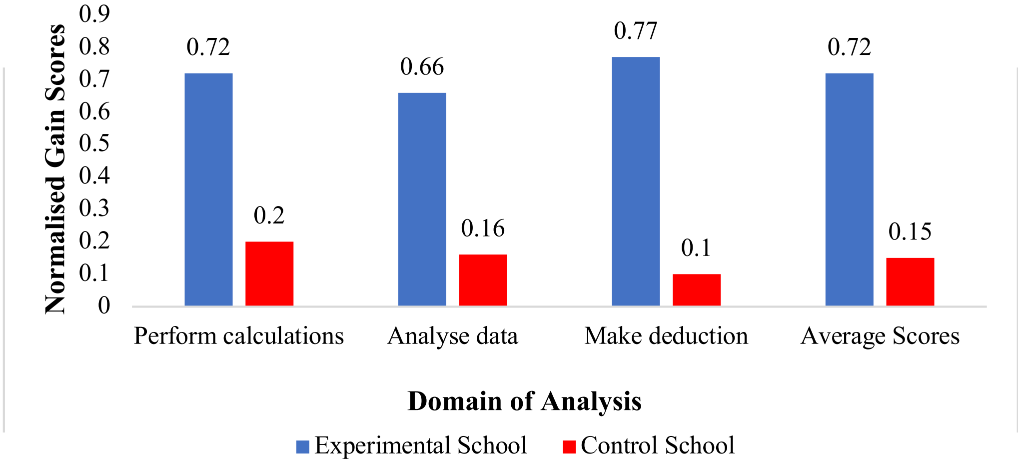

Figure 5: *Normalised gain scores in the experimental school and control school domain of analysis*

The results in Figure 5 indicate that students engaged in GIBE practical activities in the experimental school outperformed those in the control school who learned through the TBE approach. The use of GIBE in the experimental school resulted in the highest normalised gain score for students' ability to make deductions followed by the ability to perform calculations and moderate normalised gain score for ability to analyse data. In the control school, the students scored low normalised gain for the ability to perform calculations, analyse data and the ability to make deductions. A paired sample *t*-test was conducted to test if the changes from pre-test to post-test were statistically significant. Table 6 presents the results.

Table 6

Paired Sample T-test Results for the Domain of Analysis in the Experimental and the Control School

Schools	**Pre-test**			**Post-test**							
	N	*M*	*SD*	*N*	*M*	*SD*	*t*	*d*	*MD*	*Lower*	*Upper*
Experimental	49	2.06	1.78	46	7.09	1.93	-14.10	4.27	-5.20	-5.94	-4.45
Control	33	2.61	1.48	33	4.00	1.84	-3.61	1.88	-1.39	-2.18	-0.61

The results in Table 6 indicate that there was a significant increase in mean scores from the pre-test to the post-test with a p-value less than .05 ($p < .05$). The effect size of GIBE and TBE was large with Cohen's d statistic value of 4.27 and 1.88 respectively. The independent sample *t*-test was conducted to test if the difference in post-test mean scores between the experimental and the control school was significant. Table 7 presents the results.

Table 7

Independent Sample T-test Results for the Domain of Analysis in the Experimental and Control School

Experimental School			Control School									
N	*M*	*SD*	*N*	*M*	*SD*	*(df)*	*t*	*p*	*d*	*MD*	*Lower*	*Upper*
46	7.09	1.93	33	4.00	1.84	77	7.15	.000	1.63	3.09	2.23	3.95

The results in Table 7 show that there was a statistically significant difference in the mean scores for students between the experimental school and the control school. The effect size of GIBE was large with Cohen's d value of 1.63. The significant level was 0.000 ($p < .05$). These results reject the third null hypothesis (H_{03}) that the guided inquiry-based experiments have no significant effect on enhancing students' ability to analyse data in Physics experiments.

The results showed that students who were taught by using the GIBE approach in the experimental school scored higher in performing correct calculations, analysing data and stating deductions than those who learned through the TBE approach in the control group. The independent sample t-test results affirmed that the use of the GIBE approach was superior to TBE in enhancing the development of students' analytical skills. The guided-inquiry practical activities in the investigation phase of GIBE implementation might have played a vital role in contributing to the observed improvement in students' ability to perform data analysis. In this phase, students performed calculations, analysed data, organized data in tables and drew graphs, sketches and diagrams to gain information needed to state the relationships and make inferences from the experimental results. These findings in this study, align with that by Febri et al. (2020) whereby the high stake of analysis competence among the students was probably due to the use of the GIBE lab model. Similarly, Wahyuni and Analita's (2017) findings reported that the implementation of guided-inquiry laboratory experiments substantially improved students' ability to perform data analysis. After collecting data, students must organise the data into tables, diagrams and graphs to present the data in a way that supports the conclusions and accuracy of the results.

Domain of evaluation

In the domain of evaluation, the study assessed five practical skills related to students' ability to evaluate experimental results. These were students' ability to conclude the findings of the experiment, make a judgement on the accuracy of the results, suggest a suitable title and aim of the experiment, state the sources of errors and provide suggestions to improve experimental design. Figure 6 presents the normalised gain scores.

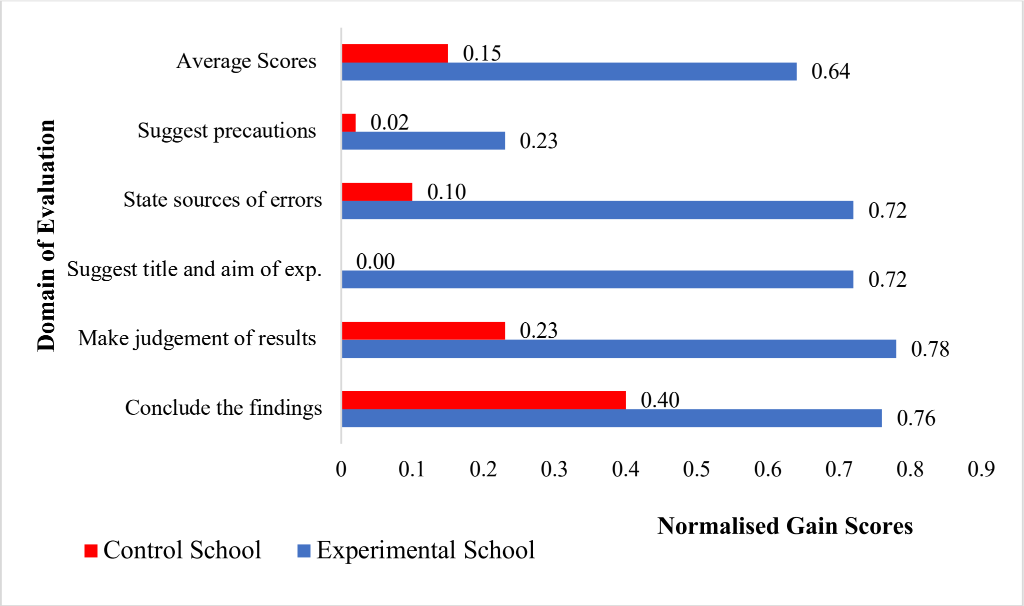

Figure 6: *Normalised gain scores in the experimental school and the control school domain of evaluation*

The results in Figure 6 indicate that the normalised gain scores were higher in the experimental school than in the control school. In the experimental school, the normalised gain score was highest for students' ability to make judgements of results followed by concluding findings, stating sources of errors and suggesting the title and aim of the experiment. While students' ability to suggest precautions scored a low normalised gain. In the control school, the students scored moderate normalised gain for the ability to conclude findings followed by low normalised gain scores for the ability to make the judgement of results, state sources of errors, and suggest precaution and zero gain for the ability to suggest suitable title and aim of the experiment. A paired sample *t*-test was performed to test if the changes from pre-test to post-test were statistically significant. The results are presented in Table 8.

Table 8

Paired Sample T-test Results for the Domain of Evaluation in Experimental and the Control School

Schools	Pre-test			Post-test							
	N	*M*	*SD*	*N*	*M*	*SD*	*t*	*d*	*MD*	*Lower*	*Upper*
Experimental	49	2.37	2.35	46	11.70	3.13	-16.61	4.96	-9.37	-10.51	-8.23
Control	33	2.73	1.99	33	4.06	2.87	-2.31	.81	-1.33	-2.51	-0.16

The results in Table 8 show a statistically significant increase in mean scores from pre-test to post-test in both the experimental school and the control school. The effect size of GIBE and TBE was large with Cohen's d values of 4.96 and .81 respectively. The independent sample *t*-test was performed to test if the difference in post-test mean scores between the experimental and the control school was significant. Table 9 presents the results.

Table 10

Independent Sample T-test Results for the Domain of Evaluation in Experimental and Control School

Experimental School			Control School									
N	*M*	*SD*	*N*	*M*	*SD*	*(df)*	*t*	*p*	*d*	*MD*	*Lower*	*Upper*
46	11.70	3.13	33	4.06	2.87	77	11.06	.000	2.50	7.64	6.26	9.01

The results in Table 9 show that, there was a statistically significant difference in the mean scores for students in the experimental school and the control school. The effect size of GIBE was large with Cohen's d value of 2.50. The value of the significant level *(p)* was 0.000 ($p < .05$) rejecting the fourth null hypothesis (H_{04}) which proposed that the guided inquiry-based experiments have no significant effect on developing students' ability to evaluate experimental results in Physics.

The results showed that students in the experimental school taught using GIBE had significantly higher mean scores than in the control school taught using TBE in the ability to conclude findings, make judgements about the experimental results, and suggest the title and aim of experiments, and the ability to state possible sources of errors in the experiment. The learning activities in the conclusion and discussion stages of GIBE implementation that encouraged students to connect explanations to scientific knowledge, and evaluate and communicate results are likely to play a vital role in enhancing students' abilities to evaluate results in the domain of evaluation. Similar claims were reported by Prihmardoyo et al. (2017) that guided inquiry laboratory-based biology modules are effective in supporting the development of student's ability to formulate experimental objectives and draw conclusions. However, the findings on the aspect of students' ability to conclude findings contradict those of Wahyuni and Analita (2017), which showed that the use of guide inquiry laboratory experiments to improve students' analytical thinking skills in chemistry resulted in low improvement in formulating conclusions. In this study, even though GIBE led to higher improvement in the four aspects of practical skills as compared to TBE, the analysis of normalised gain indicated low improvement in students' ability to explain precautions for reducing errors in the experimental design in the domain of evaluation. Students might have experienced difficulties in anticipating possible precautions to reduce errors in the experimental design.

Conclusions and Recommendations

From the study's findings, several conclusions can be drawn. While both approaches offer value in learning Physics through practical activities, the use of GIBE leads to significant gains in acquiring practical skills. Specifically, it enhances students' ability to design experiments (H01), perform experiments (H02), analyse data (H03), and evaluate experimental results (H04). In contrast, the traditional approach primarily promotes memorisation and repetition of procedures, with limited impact on the development of practical skills in Physics.

The study applied a quasi-experimental design with restricted full randomisation of participants and similar methods to assess students' acquisition of practical skills in pre-testing and post-testing during intervention. Thus, long intervals between pre-testing and post-testing could have minimized the effect. The study recommends that other pure experimental studies be conducted on other topics in physics to establish a strong generalizable finding for full adoption of GIBE in teaching and learning of Physics. In addition, the Physics teachers should be more creative and innovative in planning collaborative laboratory practical activities in the form of GIBE to foster students' acquisition of practical skills essential for effective learning of Physics. Moreover, the school administration in collaboration government should create a well-equipped Physics laboratory to support teaching and learning through GIBE practical activities.

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