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Effect of Guided Inquiry on Pre-Service Teachers' Achievement and Retention in Photosynthesis

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ABSTRACT: This study investigated the effect of Guided Inquiry (GI) on pre-service teachers' academic achievement and retention in photosynthesis. A quasi-experimental research design was used with 65 pre-service teachers, where 32 were assigned to the experimental group (EG) and 33 to the control group (CG). Data were collected using a Learners' Achievement Test and analysed using descriptive statistics: means and standard deviations, and inferential statistics, including T-tests and analysis of covariance (ANCOVA). Both groups completed a pretest, and no significant difference was recorded in prior knowledge ($p > .05$). Post-tests measured pre-service teachers' achievement and retention after teaching both groups. A T-tests showed that learners taught using GI scored significantly higher than those taught using Traditional Teaching (TT) ($p < .05$). ANCOVA, controlling pretest scores, confirmed a significant effect of the teaching approach on post-test achievements in favour of GI ($p < .05$). Differences between male and female achievements were not statistically significant ($p > .05$). The findings suggest that GI enhances conceptual understanding and retention in science education.

Keywords: Academic achievements, Traditional Teaching, Retention, Photosynthesis, Guided Inquiry

INTRODUCTION

Recent biology education research highlights challenges in learners' academic achievements and retention, particularly in complex biology topics such as photosynthesis, which involves a lot of chemical reactions. Minner et al [1] show that learners have challenges to achieve high performance but also to retain scientific knowledge over time [2], raising concerns about the effectiveness of current instructional approaches. This is especially critical for pre-service teachers, for whom achievement and retention are essential for developing accurate subject knowledge and effective teaching practices. Low conceptual mastery often leads to misconceptions and limits the ability to teach complex scientific ideas, particularly those involving abstract, microscopic, and multi-level processes such as photosynthesis [3, 4]. These challenges are common in biology topics that require integration across multiple levels of organisation, and hence, highlight the need to examine challenges in the conceptual understanding of photosynthesis. Photosynthesis is widely recognised as one of the most conceptually demanding topics in biology due to its multi-level and abstract nature. It requires students to integrate processes taking place at the microscopic and biochemical levels into a coherent framework. Often, students have challenges in understanding light-dependent reactions, electron transport processes, Adenosine Triphosphate (ATP) synthesis, and carbon fixation, which may enhance fragmented conceptual understanding [5]. In addition, students need to know chemistry well to understand the photosynthesis processes. All these compound conceptual challenges contribute to both low academic achievement and weak retention of content. Thus, confirming that strategies used in teaching may not be sufficient for conceptual understanding and retention in biology. Hence, the need for an effective teaching strategy.

Studies show that inquiry-based teaching enhances biology learning outcomes when properly guided. Furtak et al. [2] contend that inquiry teaching enhances conceptual understanding when combined with scaffolding. Research shows that GI is better than non-GI in promoting learning. Lazonder and Harmsen [6] and Minner et al. [1] found that teaching using GI enhances student engagement. Hmelo-Silver et al. [7] further emphasised that scaffolding is essential in preventing cognitive overload and supporting meaningful learning. Notwithstanding these established benefits that enhance learning through GI, learners continue to experience persistent difficulties in understanding photosynthesis concepts.

These studies reveal several remaining research gaps, including, firstly, studies focusing on academic low achievement or conceptual understanding, with limited attention to long-term retention. Minner et al. [1] and Furtak et al. [2], applying meta-analyses, show that GI measures short-period post-test gains rather than delayed retention. Secondly, there is a dearth of studies integrating achievement with retention. Furthermore, Lazonder and Harmsen [6] contend that inquiry research often examines isolated cognitive variables and not long-term studies, and limits progressive conceptual change. Moreover, Hmelo-Silver et al. [7] further emphasise that without integrated assessment approaches, it is difficult to evaluate whether inquiry learning leads to stable knowledge construction. Thirdly, there is limited research on GI use by biology pre-service teachers in Sub-Saharan Africa, where Traditional Teaching (TT) still dominates classroom practices [8].

Finally, studies on GI have largely focused on short-term academic low achievement, with limited attention to long-term retention of biological concepts. In addition, few studies have integrated both achievement and retention within a single analytical framework. Furthermore, there is limited evidence from pre-service teachers' contexts in Sub-Saharan Africa, particularly in relation to complex topics such as photosynthesis. These gaps suggest that existing research does not fully capture the effects of GI across time and context.

The novelty in this study is in the integration of both academic achievement and retention as outcome measures in examining the effectiveness of Guided Inquiry (GI) compared to Traditional Teaching (TT). It further contributes context-specific evidence from pre-service biology teachers in a developing education setting, focusing on the conceptually demanding topic of photosynthesis. In addition, the study examines gender differences in learning outcomes, thereby extending current understanding of equity in inquiry-based science teaching.

RESEARCH METHODS

Research Design

This study used a quasi-experimental design with a control group to examine the effect of GI on students' academic achievement compared to Traditional Teaching (TT) [17, 18]. This design was befitting because intact classes were used, allowing instruction to occur under natural classroom conditions, at the same time minimizing disruptions associated with random assignment [17]. Quasi-experimental designs are used widely in educational research when randomisation is not feasible, but causal comparisons between groups are required [19, 20].

Participant/Respondents

The sample of this study comprised 65 third-year pre-service teachers enrolled in a Bachelor of Education program at a university in South Africa. The researcher asked 65 students to volunteer to form two groups: an experimental group (EG = 32, 16 males and 16 females) and a control group (CG = 33, 16 males and 17 females). These participants had already completed school observation in their first year and teaching practice in their second year and were preparing to undertake a second teaching practice placement. Consequently, they were considered an appropriate cohort because they required practical pedagogical skills to apply in authentic classroom contexts.

Instruments

A pre- and post-test instrument consisting of 15 questions was used to collect data (Appendix 1) and a rubric for open-ended questions (Appendix 2). Three experts, two Physical Sciences teachers and one lecturer checked pre-post-tests for readability and content validity. For reliability, a pilot study was conducted with 8 learners who were not part of the study, and any questions that were not clear were adjusted for clarity before the instruments were administered. The Cronbach Alpha coefficient for the instrument was .83, which was good enough for the study [21, 22].

Data Collection process

A pre-test was administered to the EG and the CG to determine their level of understanding before the intervention. EG and CG were taught at the beginning of the semester for four weeks by the author to avoid teacher variations. Four periods were used for the study, each lasting 1.5 hours, for a total of 6 hours in four weeks. These hours were sufficient because earlier studies using three hours of GI have been reported to have a long-term impact on learning [23]. Even a few moments of active learning can produce measurable gains in conceptual understanding [24]. Also, Freeman et al. [25] and Theobald et al. [26] in different settings used meta-analytic structured learning activities, which yielded positive academic achievements. Six hours were enough for GI intervention to show enhanced academic improvements in science learning [24, 25]. Therefore, the six-hours GI pre-service teachers were exposed to in this study are considered adequate to generate measurable differences between the EG within a controlled quasi-experimental design.

The experimental group was taught using GI through structured, teacher-designed activities involving group discussions, problem-solving, and hands-on tasks. The structured teaching involved seven stages by Kuhlthau [27]: (i) initiation, where the topic was introduced through teacher-learner interaction; (ii) selection, where learners identified inquiry directions guided by set questions; (iii) exploration, where learners searched and examined relevant information sources; (iv) formulation of focus, where learners reworked and revised their work several times; (v) collected information, where learners organised and synthesised relevant knowledge; (vi) presented their findings in groups in the class; and (vii) evaluation, where presentations were assessed based on accuracy, depth, and clarity [27]. Throughout these stages, the teacher facilitated the process by GI activities, supporting access to learning resources, and monitoring group work.

Data analysis

Data from the pre-test and post-test were analysed descriptively using means and standard deviations (SD) to summarise learners' performance in both the experimental and control groups [28]. Before conducting the main inferential analysis, the assumption of normality was examined for the achievement and retention scores using the Shapiro-Wilk test to determine whether the data were approximately normally distributed. Inferential statistics were then applied to determine group differences. T-tests were used to compare post-test achievement between the experimental and control groups, as well as between male and female participants [28].

Analysis of Covariance (ANCOVA) was used to test pre-test differences and to determine the effect of the intervention on post-test outcomes while adjusting for baseline scores [29]. In addition, Cohen's d was calculated to determine the magnitude of the observed effects [30]. Statistical software was used as a tool to analyse data.

Ethical Considerations

The study followed standard ethical principles for educational research involving human participants [19]. Since participation was voluntary, participants were informed that they could withdraw if need be. Informed consent was obtained. Participants' names were used in class activities to assist the researcher in tracking retention after four months, but participants were anonymised in reporting. All participants could withdraw at any time without academic penalty. The study was supported by the author's Internal Research Chair Grant (R792, 2012–2018).

RESULT AND DISCUSSION

Result of Quantitative Analysis

The results of this study are organised in Tables 1-6 and address the three research questions on academic achievement, retention in photosynthesis, and gender differences in learning outcomes. Table 1 shows the results of the normality tests for pre-test and post-test scores, showing that the data for both experimental and control groups were normally distributed. Kolmogorov-Smirnov and Shapiro-Wilk tests yielded non-significant values ($p > .05$), implying that the assumption of normality was satisfied for all datasets. This confirms the appropriateness of parametric statistical tests for further analysis. Table 2 presents the results of both pre-test and post-test comparisons between the EG and CG. At the pre-test level, there were no statistically significant differences between the EG and CG, indicating that the two groups were comparable in terms of prior knowledge before the teaching intervention. However, at the post-test level, statistically significant differences were observed in favour of the EG, with a large effect size, indicating that learners exposed to GI achieved better in photosynthesis than those taught using traditional teaching methods. Table 3 further confirms baseline equivalence, showing that the EG and CG did not differ in their initial achievement before intervention. This strengthens the validity of attributing post-intervention differences to the instructional treatment. In relation to Research Question 1 (academic achievement), Table 2 (post-test results) and Table 4 (pre-test-post-test gains) show that the EG demonstrated significantly greater improvement compared to the CG. Also, the results show large effect sizes using Cohen's d ($d = 1.53$). The results show large effect sizes for the EG, with partial η^2 values ranging from .60 to .80, indicating that GI is highly likely to account for a large variance in learners' understanding of photosynthesis and academic achievement. Regarding research question 2 on retention, ANCOVA results (Table 5) show that the intervention had a statistically significant effect on post-test performance even after controlling for pre-test scores. Table 6 shows no statistical differences between males and females in EG $t(30) = -0.17$, ($p = .87$). Finally, across the analyses, no statistically significant gender differences were observed in academic achievements. The rest of the results are presented in the following section according to Tables 1-6, with each table aligned to the research questions; collectively, the findings answer the three research questions on academic achievement, retention, and gender differences.

The Kolmogorov-Smirnov and Shapiro-Wilk tests of normality were used to assess whether the pre-test and post-test scores for the experimental and control groups met the assumptions required for parametric tests (Table 1).

TABLE 1. Shapiro-Wilk Test of Normality for Pretest and Posttest Scores in Experimental and Control Groups

Group	Time point	n	Kolmogorov–mirnov D	p	Shapiro–Wilk W	p
EG	Pretest	32	.136	.137	.957	.227
CG	Pretest	33	.159	.033	.961	.273
EG	Posttest	32	.121	.200*	.957	.250
CG	Posttest	33	.141	.122	.958	.252

Table 1, the Shapiro–Wilk test indicates that all distributions were not significantly different from normal for the EG pretest (W = .957, p = .227), CG pretest (W = .961, p = .273); EG post-test (W = .957, p = .250), and CG post-test (W = .958, p = .252). Although the Kolmogorov-Smirnov test shows a significant deviation from normality for the CG pretest (D = .159, p = .033), the remaining results were non-significant (p > .05). Since the Shapiro-Wilk test is considered more robust for small to moderate sample sizes, the overall results indicate that the assumption of normality was met across all groups and time points. The findings show that GI improved academic achievement. The normality results (Table 1), which included both pretest and post-test scores, confirmed that the data were normally distributed. This satisfied the assumptions required for parametric tests. This finding aligns with Field [28], who notes that normality is a key prerequisite for reliable use of t-tests and ANCOVA in educational research. The pretest scores of the control and experimental groups prior to the intervention were analysed to determine baseline equivalence between the two groups before treatment (Table 2).

TABLE 2. Pretest scores for CG and EG before the intervention

Test	Group	No	Mean	Std Dev	t	p	Cohen d
Pre-test	EG	32	44,84	6,27	-.67	.00	-.17
	CG	33	45,70	5,95			

Table 2 shows no statistically significant difference between the EC and CG groups, $t(63) = -0.67$, $p = .508$. The EG (M = 44.84, SD = 6.27, n = 32) had slightly lower scores than the CG (M = 45.70, SD = 5.95, n = 33). The pretest results, Table 2, supported by Table 3, showed no significant differences between the EG and CG before the teaching intervention. The post-test results in Table 4 revealed statistically significant differences in favour of EG, with a large effect size of 1.57. It is most likely that GI instruction significantly improved learners' academic achievement in photosynthesis compared to traditional teaching. This finding agrees with Furtak et al. [2], who found that GI enhances conceptual understanding, and Lazonder and Harmsen [6], who reported that structured inquiry was more effective than unguided discovery. It implies that the better achievement in the EG is in line with the constructivist's theory [15], where individuals learn by active engagement. Also, the results are supported by Aditomo and Klieme [29] and Chikaluma et al. [30], who, using inquiry-based learning, show improved academic achievements. Similarly, Kersting et al. [31], who scaffolded students in guided inquiry, reported improvements in learners' construction and application skills. The independent samples t-test was conducted to compare the pretest and posttest scores between the experimental and control groups to determine whether there were statistically significant differences in performance (Table 3).

TABLE 3. Independent Samples t-test for CG Pre-test and Post-test Scores.

Test	Group	No	Mean	Std Dev	t	p	Cohen d
Pre-test	CG	33	45.70	5.95	-.06	.96	-.02
Post-test	CG	33	45.79	5.89	-.06		

Table 3 shows that there was no difference between the pre-test and post-test for the CG. The pre-test mean score (M = 45.70, SD = 5.95) was almost identical to the post-test mean score (M = 45.79, SD = 5.89); and the t-test was t(64) = −.06, p =,96 show negligible differences between the two. In addition, the effect size (Cohen's d = −.02) suggests that the observed difference is not meaningful.

Thus, these results suggest that there was no meaningful change in the CG performance between the pre-test and post-test achievements.

The findings in Table 3 indicate that there was no statistically significant difference between the pre-test and post-test scores of the CG. This suggests that TT alone may be insufficient to promote substantial learning gains, especially in topics that require conceptual understanding like photosynthesis. These findings are consistent with prior studies indicating that guided inquiry teaching is more effective than traditional teaching in improving students' academic achievement, particularly when adequate teacher guidance and scaffolding are provided [1, 14]. Although GI is beneficial for achievement and retention, recent evidence suggests that its effectiveness is not universal. Areepattamannil et al. [32] noted that guided inquiry is most effective when supported by explicit explanations and strong teacher guidance. Some studies indicate that inquiry approaches can produce weaker achievement outcomes when insufficiently scaffolded, when teachers are inadequately prepared, or when cognitive demands exceed students' readiness levels. For example, Gómez and Suárez [33] found a negative association between inquiry-based instruction and science achievement in large-scale PISA data, although critical thinking outcomes were positive. Similarly, Skulmowski and Xu [34] and Kirschner et al. [35] argued that learning approaches with insufficient guidance may place excessive cognitive demands on novice learners, thereby reducing learning effectiveness. Thus, GI may be effective under certain conditions rather than being always superior to TT methods.

The paired T-test results comparing pretest and posttest scores within the EG and CG to determine whether there were significant changes in performance over time (Table 4).

TABLE 4. Pretest and post-test for

Group	Test	No	Mean	Std Dev	t	p	Cohen d
CG	Pretest	33	45.70	5.96	-3.08	.99	.76
	Post test	33	45.79	5.89			
EG	Pretest	32	44.84	6.31	6.17	.00	1.53
	Post test	32	54.41	6.18			

Table 4 shows that for the CG, there was a slight increase from pre-test ($M = 45{,}70$, $SD = 5{,}96$) to post-test ($M = 45{,}79$, $SD = 5{,}89$); however, this change was not statistically significant, $t = -3{,}08$, $p = 99$, $d = 0{,}76$, suggesting a medium improvement from pre-test to post-test. Conversely, EG showed a substantial improvement from pre-test ($M = 44{,}84$, $SD = 6{,}31$) to post-test ($M = 54{,}41$, $SD = 6.17$), which was statistically significant, $t = 6{,}17$, $p < .001$, with a large effect size, $d = 1{,}53$. These findings suggest that the intervention had a strong positive impact on the performance of EG compared to CG.

The within-group analysis (Table 4) showed that the EG demonstrated significantly greater improvement from pre-test to post-test compared to the CG. It indicates stronger learning achievement, most likely due to the GI intervention. This observation is supported by Minner et al. [1], who found that GI improves understanding of content. Similarly, Hmelo-Silver et al. [7] and Adler & Sarsour [36] emphasise that scaffolding reduces cognitive overload and supports integration of complex scientific concepts, such as photosynthesis, to enhance conceptual development. ANCOVA was used to determine the effect of the intervention on EG post-test score with pre-test as a covariate (Table 5).

TABLE 5. Analysis of Covariance (ANCOVA) for Post-test Scores

Source	SS	df	MS	F	p	ηp^2
Intercept	79.85	1	79.85	2.59	.270	.60
Pretest (Covariate)	1963.37	1	1963.37	256.55	.001	.81
Intervention	1332.16	1	1332.16	174.07	.001	.74
Error	474.48	62	7.65			

Table 5 shows that the covariate (pre-test) was a significant predictor of post-test scores, $F(1, 62) = 256.55$, $p < ,001$, partial $\eta^2 = 81$, indicating a very large relationship between baseline and post-intervention performance. More importantly, the intervention in the experimental group (EG) had a statistically significant effect on post-test scores, $F(1, 62) = 174.07$, $p < .001$, partial $\eta^2 = ,74$, demonstrating a strong treatment effect. It indicates that GI contributed to the EG pre-service teachers' achievement. This finding is consistent with Lazonder and Harmsen [6], who argue that GI leads to stronger cognitive outcomes when properly structured, and with cognitive load theory, which suggests that structured instructional support enhances meaningful learning by reducing extraneous load [34]. Furthermore, effect size estimates are used to determine the practical significance of the intervention on learners' outcomes. The results show large effect sizes for EG, with partial η^2 values ranging from

.60 to .80. This suggests that the achievements were due to GI. These findings corroborate Cohen's d values of -,02 and 1.53 in tables 3 and 4, respectively. In contrast, the CG taught using Traditional Teaching (TT) shows negligible gains that are not statistically significant. Overall, these results provide additional evidence that the GI intervention was associated with stronger pre-service teachers' achievements, at least in this study.

An independent samples t-test was conducted to compare the post-test mean scores of male and female students in the experimental group to determine whether significant gender differences existed after exposure to guided inquiry instruction (Table 6).

TABLE 6. T-test comparing male and female post-test scores in EG

Test	Group	n	Mean	Std Dev	t	p	Cohen d
EG	Male	16	45.59	5.87	-.11	.53	-0.02
	Female	16	45.81	6.22	-.11		

Table 6 shows that EG males (n = 16, M = 45,59, SD = 5,87) had slightly higher mean scores compared to EG females (n = 16, M = 45,81, SD = 6,22). However, the independent samples t-test showed that this difference was not statistically significant, t(30) = -11, p = ,53. This suggests that there is no meaningful difference between males and females in their performance when taught using GI

The absence of significant gender differences in post-test results for EG (Table 6) suggests that GI is equally effective for both male and female pre-service teachers in improving academic achievement and retention. This aligns with Chikaluma et al [30], where structured inquiry promotes similar achievements among genders when appropriate scaffolding is provided. Overall, the findings suggest that GI is associated with improved academic achievement and learning gains in biology education, particularly in the learning of photosynthesis, compared to traditional teaching approaches.

Despite the positive effects observed in this study, recent research indicates that the effect of EG depends on context rather than being universally accepted [37, 30]. Also, these studies show that inquiry-based instruction is not always superior compared to TT, especially when students have knowledge gaps from their earlier academic levels [29, 37]. In such cases, students exhibit information learning challenges, leading to a superficial understanding of concepts.

A major limitation highlighted in recent literature is that GI can become less effective when it is implemented without enough structure and teacher guidance. In that case, there is an academic overload where students engage in many complex activities during the learning process, resulting in weak conceptual understanding and retention [38]. In addition, low-quality content, limited teaching strategies and teaching resources may wane the effectiveness of GI [31, 30]. Similarly, de Jong et al. [39] show that less scaffolded GI yields minimal achievements compared to structured teaching, especially in poorly resourced environments.

Conversely, the present study demonstrates high academic achievement for GI, suggesting that the structured GI design used in the EG intervention improved retention. The GI in this study provided systematic support that helped pre-service teachers to connect abstract biological processes in photosynthesis, thereby reducing cognitive overload and enhancing conceptual integration. This may explain the significant improvements observed in both achievement and retention outcomes.

The lack of significant gender differences suggests that GI provide similar learning opportunities, reinforcing its pedagogical value in classroom settings. However, the results from this study should be interpreted with care, as contextual and instructional factors may influence equity achievements in different environments. Thus, notwithstanding limitations GI exhibited in the literature, the results of this study suggest that when GI is appropriately scaffolded, it can be an effective teaching strategy for improving academic achievement and retention when dealing with complex biology topics like photosynthesis.

The study makes several contributions to biology education. It provides empirical evidence that GI may enhance academic achievement and improve knowledge retention. GI supports equitable learning achievements among genders. It aligns teaching and learning environments that exert a stronger influence on learners' achievement than gender alone [40]. This study contributes to the meta-analytic evidence that inquiry-based instruction improves academic achievements compared to traditional teaching approaches [2, 6].

Another contribution is the pre-service teachers' engagement in teaching complex biological concepts in plant physiological processes, such as the C3 and C4 systems. This aligns with inquiry-based strategies that promote conceptual understanding [41, 42]. However, these effects are likely dependent on the level of scaffolding and instructional design provided.

Limitations of the Study

Limitations of this study are: 1) GI lasted four weeks, which is not sufficient to capture long-term retention. 2) The sample size of 65 pre-service teachers was small and drawn from a single institution, limiting the generalisation to pre-service teacher populations or other educational contexts. 3) Although classroom conditions were controlled as much as possible, informal interactions among participants outside the structured learning environment may have influenced learning outcomes, introducing uncontrolled variability. Overall, this study offers empirical evidence in a pre-service teacher education setting. Thus, contributing to ongoing discussions on the role of GI pedagogy in promoting conceptual understanding and engagement in biology education.

CONCLUSION

The study concludes that GI improves EG academic achievement and retention for pre-service teachers. However, this conclusion should be treated with reservations due to contextual and pedagogical limitations. The results also indicate that GI may contribute to more equitable learning outcomes, as no significant gender differences were observed among genders. Overall, the study provides supportive context-bound evidence for the use of GI in biology education, particularly in pre-service teacher training. Future research should consider longitudinal designs, larger and more diverse samples, and multiple biology topics to establish further the long-term impact of GI on achievement and retention among pre-service teachers.

Authors'contribution

- ***Conceptualization***: *Israel Kibirige;*
- ***Data curation***: *Israel Kibirige;*
- ***Formal Analysis***: *Israel Kibirige;*
- ***Funding acquisition***: *Israel Kibirige;*
- ***Investigation***: *Israel Kibirige;*
- ***Methodology***: *Israel Kibirige;*
- ***Project administration***: *Israel Kibirige;*
- ***Resources***: *Israel Kibirige;*
- ***Supervision***: *N/A;*
- ***Validation***: *Israel Kibirig;*
- ***Visualization***: *Israel Kibirige;*
- ***Writing – original draft***: *Israel Kibirige;*
- ***Writing – review & editing***: *Israel Kibirige;*

All authors have read and agreed to the published version of the manuscript.

Ethics Statement

This research involved human subjects who had given informed consent to participate. All participants received treatment in accordance with their rights, dignity, and applicable research ethics principles.

Data availability statement

The data will be available upon request. All data sets were generated or analyzed in the current study.

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Conflicts of Interest

The author declares no conflicts of interest.

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