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Résumé de l'article

This study investigated the role of interactivity on the protégé effect, and explored how biology teachers can utilize it in their classrooms to reduce rote learning and facilitate long-term retention. This investigation utilized the generative learning theory, and adopted a non-equivalent quasi- experimental research design involving 60 students. The instruments used for this study include a stimulus instrument titled, Teachers' Instructional Guide on Ecology of Population (TIGEP), which was used as guide for teaching ecology with the protégé effect, and three response instruments. The first, the Population Ecology Requirement Test (PERT), was used to show the required knowledge for the respondents on the protégé effect, while the second and third, the Population Ecology Achievement Tests (PEATs; version 1 and 2), helped to assess the learners' performances. Results, obtained using analysis of covariance and Bonferroni post-hoc analysis, indicated that the protégé effect significantly influenced the performances of students on immediate tests ($Fcal = F(3,55) = 24.47 > Ftab = 8.57$, $p < 0.001$) and on the long-term retention of Biology concepts ($Fcal = F(3,55) = 16.25 > Ftab = 8.57$, $p < 0.001$). This study showed that interactivity, via the protégé effect, provides a strong indication for improving academic performance and retention of learned concepts in biology, as it assists in consolidating and integrating learned concepts.

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Abstract

This study investigated the role of interactivity on the protégé effect, and explored how biology teachers can utilize it in their classrooms to reduce rote learning and facilitate long-term retention. This investigation utilized the generative learning theory, and adopted a non-equivalent quasi-experimental research design involving 60 students. The instruments used for this study include a stimulus instrument titled, Teachers' Instructional Guide on Ecology of Population (TIGEP), which was used as guide for teaching ecology with the protégé effect, and three response instruments. The first, the Population Ecology Requirement Test (PERT), was used to show the required knowledge for the respondents on the protégé effect, while the second and third, the Population Ecology Achievement Tests (PEATs; version 1 and 2), helped to assess the learners' performances. Results, obtained using analysis of covariance and Bonferroni post-hoc analysis, indicated that the protégé effect significantly influenced the performances of students on immediate tests ($F_{cal} = F_{(3,55)} = 24.47 > F_{tab} = 8.57$, $p < 0.001$) and on the long-term retention of Biology concepts ($F_{cal} = F_{(3,55)} = 16.25 > F_{tab} = 8.57$, $p < 0.001$). This study showed that interactivity, via the protégé effect, provides a strong indication for improving academic performance and retention of learned concepts in biology, as it assists in consolidating and integrating learned concepts.

Introduction

Biology is not an isolated discipline (Gilbert & Hadfield, 2022). Its teaching should integrate political, social, and contemporary paradigms to provide a holistic understanding (Chamany et al., 2008; Harris & McDade, 2018). In line with this, the National Policy on Education in Nigeria emphasizes that secondary school biology education should prepare students for meaningful living in society and higher education. To achieve these objectives, biology education must go beyond abstract lessons, enabling students to connect classroom learning with real-life experiences (Gilbert & Fausto-Sterling, 2003).

However, the traditional expository teaching method, characterized by direct instruction, remains dominant in classrooms, due to factors such as teachers' personalities, varying levels of subject mastery, curriculum overload, and limited access to instructional materials (Raji, 2017). This method focuses on delivering information while students passively take notes (Kozanitis & Nenciovici, 2023; Loughlin & Lindberg-Sand, 2023; Maheshwari, 2013). While expository methods save time (Nasution, 2020), they often induce passivity, fail to align with diverse learning styles, and promote memorization over deep understanding (Funmilayo & Odukoya, 2019; Landøy et al., 2020).

Such emphasis on memorization leads to a superficial grasp of concepts, low interest in biology, and a focus on merely passing examinations—often resulting in a temporary increase in knowledge utilization (Bailon, 2023; Davis & Francis, 2023; Güneş, 2020; Ishartono et al., 2019; Klemm, 2007; Mayer, 2002). Shekar (2018) highlights that students reliant on rote learning frequently forget most information after examinations, a side effect of the "testing effect," where learning is driven solely by the desire to pass tests (Binks, 2018; Roediger & Karpicke, 2006).

This phenomenon can lead to anxiety, reducing long-term retention of previously learned concepts, limiting knowledge transfer, and affecting students' performance in higher education and their ability to tackle future challenges (Lai, 2023). Ultimately, these outcomes undermine the goals of secondary education as outlined in the National Policy on Education.

Effective retention and the real-world application of biology concepts require more than expository methods. They involve fostering thorough theoretical understanding, practical applications, and sustained recall. Teachers must adopt teaching strategies that spark learners' interest, encourage comprehension, and promote long-term retention, which is critical for applying knowledge to real-life complexities.

Several methods, such as the Socratic method, discovery learning (Ishartono et al., 2019), and mixed techniques, like spaced repetition, have been proposed to enhance retention and reduce rote learning. However, these methods also have limitations. For instance, the Socratic method, which involves questioning and answering in a challenging argumentative dialogue, may bore uninvolved learners (Dinerstein, 2011), overwhelm participants (Curcio, 2024; Mintz, 2018; Roberts & Reamy, 2014), or intimidate students with limited prior knowledge (Oyler & Romanelli, 2014). In some cases, it can become overly authoritative (Sokoloff, 2019), making it unsuitable for diverse learners, especially children (Grondin, 2018).

In like manner, students using spaced repetition still struggle with tasks related to transfer of learning and application (Smith & Scarf, 2017). Likewise, some studies like Goossens et al. (2016) found no significant difference in students' performance when subjected to long- or short-spaced repetitions. Discovery learning, as well, has been known to create misconceptions and cognitive overload in the absence of an initial framework for novice learners (Kotee & Nguyen, 2021). Therefore, there is still a constant search for teaching strategies that will ensure permanent learning and true comprehension. The need compounds for a subject, like biology, where students acquire knowledge about delicate living systems (Coxon et al., 2019). However, the golden truth is that no teaching strategy can be a panacea (Chew & Cerbin, 2020), though some methods better foster engagement and lasting learning. Methods adopting the protégé effect are notable examples.

Over the years, researchers like Annis (1983), Coleman et al. (1997), Matsuda et al. (2013), Fiorella and Mayer (2013a), Kobayashi (2018), and others have realized that people tend to increase efforts towards learning when they plan or expect to teach others, than when learning for just themselves. This improvement in performance, because of the apparent expectancy to teach, is called the protégé effect. In academic situations, Kobayashi (2018) noted that it can stimulate "teacher-role'" students who generatively and constructively process learning materials more than conventional learners. Thus, it can help these learners to organize important information, integrate it with prior knowledge, and reflect on their own comprehension. All these happen as the students read to find a way to teach others. By so doing, the protégé effect can enhance learning (Daou et al., 2016; Duran, 2017).

However, while the expectancy to teach may indeed push students to browse learning materials, certain cases happen where such students only superficially retain few concepts to impress others. Here, learning will be less effective and subsequently defeats the primary aim of protégé conditioning (Hoogerheide et al., 2016; Koh et al., 2018; Roscoe and Chi, 2007). Although, while teaching, Kobayashi (2018) noted that the more the teacher-role students provide explanations, ask and answer questions, and then give and receive feedback, the more they learn and the more effective is the protégé effect. All these interactions between the teacher-role students and the tutees are called interactivity, and the more it exists, the better the learning outcomes (Kobayashi, 2018). Thus, the protégé effect can broadly meet the intentional learning of concepts associated with preparing/expecting to teach, teaching, and building interactivity in the teaching process. This operational extension of the protégé effect is the working term for this study.

A few teaching methods, such as presentations and group discussion, already incorporate aspects of the protégé effect. For instance, in the modern presentation technique, students prepare by studying certain concepts beforehand, and presenting them to others, using informative computer slides. However, in Nigeria, many secondary schools lack the resources to create and power such slides (Ahmed, 2020). In the few schools that do have these resources, teachers may lack the expertise to guide students in creating effective visual presentations (Moemeke, 2019; Omiko, 2016). Consequently, many teachers opt against using this method.

Similarly, group discussion methods face challenges. Teachers often struggle to manage group interactions, or ensure that disengaged students remain involved (Mesfin & Adimasu, 2020). As a result, many biology teachers abandon this method, viewing it as either time-consuming or difficult to implement. They often revert to the expository method, perpetuating the cycle of rote learning, and highlighting the ongoing need for reforms in teaching procedures.

However, this does not mean that all protégé-based teaching techniques are ineffective. Instead, such active learning approaches are frequently neglected, due to limited teaching time, curriculum demands, or a lack of mentoring skills among teachers (Lin, 2024). Moreover, the protégé effect differs from approaches, like presentation and group discussion, in its emphasis on teaching expectancy and the role of interactivity. It also varies slightly from peer tutoring, when students who take on a teaching role do not always expect to teach in advance, whereas teaching expectancy and preparation are prerequisites for protégé-based methods (Bowman-Perrott et al., 2013; Toppings, 2020).

In biology classes, rote learning is still a problem that hinders students' long-term comprehension and retention of difficult ideas. Learners, frequently, are not actively engaged by traditional teaching approaches in ways that support meaningful learning and long-term retention. One hopeful solution to this problem is the protégé effect, a phenomenon where pupils learn more effectively by instructing others. However, the degree of engagement included in the learning process may determine how effective it is. To promote better academic achievement and lessen reliance on rote memorization, teachers must understand how interactivity amplifies the retention benefits of the protégé effect and how to incorporate this technique into their lessons.

On that premise, this study is dedicated to confirming whether the performance-enhancing abilities of the protégé effect transcends the novelty effect and can work long-term. It also hopes to bring clarity on what aspect of the protégé effect contributes to learning and in what way. Hence, some parts of this study will attempt to explain why interactivity, as proposed by Kobayashi (2018), is vital to enhancing the performance of interactive teacher-role students over students in the expectancy, non-interactive teaching and conventional groups. Additionally, this research will shed light on how protégé effect can be used to deliver instructions in biology classrooms.

Purpose of the Study

The study aims to explain the role of interactivity on the learning benefits of the protégé effect and explore how biology teachers can utilise it in their classrooms to reduce rote learning. To achieve this, this study will specifically:

i. determine the effect of the protégé effect on the improvement of students' academic performance in biology and the long-term retention of biology concepts; and
ii. determine how interactivity affects the retention benefits of the protégé effect.

Research Hypotheses

In light of the objectives, the following null hypotheses will be assessed in this study:

Ho1: There is no significant difference in the performance of students taught and tested without the protégé effect and those taught and tested under protégé conditioning.

Ho2: There is no significant difference in the performance of all the conditioned students and those without protégé conditioning after a week.

Significance of the Study

This study aims to evaluate the protégé effect's retention-enhancing ability, and expand knowledge on interactivity mechanisms. Specifically, it will benefit secondary-school biology teachers, by providing innovative teaching strategies to boost student interest and retention, enhance classroom interactivity, and diversify assessment methods beyond traditional tests. For students, this study will demonstrate the effectiveness of preparing to teach and teaching peers, which fosters deeper learning while improving performance. School authorities will gain insights into improved weekly activities, such as pre-planned student-led teaching sessions, justification for increased biology class time, and better formative assessment practices. Teacher-training institutions will become aware of the methods to promote long-term learning, encouraging future teachers to adopt protégé-based teaching methods. Curriculum planners will receive guidance on incorporating protégé-based interactive techniques into curricula, making them more activity-based and learner-centred.

Lastly, researchers will benefit from contributions to empirical studies on the protégé effect, exploring its effectiveness and influencing factors.

Materials and Methods

Research Design

The research design adopted a non-equivalent quasi-experimental approach. This allowed the researcher to examine the protégé effect by treating the participants to the protégé-based methods, and exploring the different effects on the participants' performance in an immediate test and a delayed test. To further achieve the objectives, the three major aspects of the protégé effect (learning-by-simply-preparing-to-teach, learning-by-noninteractive-teaching, and learning-by-interactive-teaching) were considered.

Participants underwent testing before and following the intervention to address early disparities and more effectively evaluate the treatment's efficacy. They were additionally paired according to demographic parameters. To mitigate bias, participants were oblivious to their group allocations, while instructors received training to maintain uniform methodologies throughout both groups. Furthermore, external variables, including the atmosphere, materials, and time of day were regulated.

Collectively, this study regarded the three aspects of the protégé-based methods, and the participants were said to be under protégé conditioning. Hence, those who were not exposed to this, and taught, instead, using the conventional method (lecture) were said to be in the control group. Participants were randomly assigned to these groups. For further clarity, the table below provides a summary of the protégé conditioning groups and the control groups:

Table 1: Schematics of the research design.

Independent Variable	Teaching Methods	Non-Conditioning	1. Control Group (Conventional Lecture Method; CG).
		Protégé Conditioning	2. Learning-by-simply-preparing-to-teach group (Expectancy Group) (EG_1).
			3. Learning-by-noninteractive-teaching group (EG_2).
			4. Learning-by-interactive-teaching group (EG_3).
Dependent Variable	Participants' Performance		1. Immediate test (Post-test-1).
			2. Delayed test (after a week; Post-test-2).

Furthermore, the independent variable is the teaching method which includes all the four instructional strategies. The dependent variables are the participants' performance in the immediate and delayed tests. Population ecology was the topic of instruction. The pre-test score (Population Ecology Requirement Test-PERT), which estimated the participants' previous knowledge of ecology, was considered a covariate. The post-test-1 and post-test-2 scores of the participants in the Population Ecology Achievement Test (PEAT) served as the performance of the participants on both the immediate and delayed tests, respectively.

Table 2: Layout of the research design.

Groups	Pre-test	Treatment	Post-test-1 (Immediate test)	Post-test-2 (Delayed test)
EG1	O1	X1	O2	O3
EG2	O1	X2	O2	O3
EG3	O1	X3	O2	O3
CG	O1	-----	O2	O3

Where:

EG1 = Experimental group one
EG2 = Experimental group two
EG3 = Experimental group three
CG = Control Group

O1 = Pre-test administered to all groups
O2 = Immediate post-test administered to all groups
O3 = Delayed post-test administered to all groups
X1= Treatment for experimental group one (teaching expectancy)

X2 = Treatment for experimental group two (non-interactive teaching)
X3 = Treatment for experimental group three (interactive teaching)

Population, Sample and Sampling Technique

The population includes all senior secondary biology students in Ile-Ife, Osun, Nigeria, while the target population was all senior secondary school two (SSS II) biology students in Ife Central. The sample comprised 60 SSS II students. These participants were appropriate, because of assured exposure to knowledge prerequisites for Ecology of Population. The topic was chosen because it is one of the most difficult biology topics stated in the West Africa Examination Council (WAEC) Chief Examiner's report (2014-2021).

Purposive sampling was employed in selecting one private and one public school to prevent restriction only to schools with high admission standards and ensure a spectrum of learners. The two schools were selected based on whether they had an SSS II biology class size above 30. The students were then randomly assigned into EG1, EG2, EG3 and the CG.

As in Table 1, participants conditioned with the mere expectancy/preparation to teach, but without teaching before taking tests, fell into EG1. Those who expected to teach and taught without interacting with their tutees, or with an imaginary audience, fell into EG2, and those who expected to teach, and had an interactive teaching session with their tutees, fell into EG3. Finally, the CG were taught using only the conventional method and then tested.

Research Instruments

Design of Research Instruments Four research instruments were utilized in this study. One is a stimulus instrument titled, Teachers' Instructional Guide on Ecology of Population (TIGEP), and the other three (3) are response instruments. The TIGEP is a researcher-designed lesson plan for teaching population ecology to the participants.

The response instruments were:

- Population Ecology Requirement Test (PERT)
- Population Ecology Achievement Tests (PEATs; version 1 and 2)

The PEATs and PERT were also researcher-designed. The PERT was the pre-test for estimating previous knowledge of ecology and as a covariate. It was used to determine the participants' achievement after being taught. Two different, but correlated, versions of PEAT were used for the post-test-1 (immediate test) and post-test-2 (delayed test; after a week). Each version of PEAT consisted of 25 multiple-choice test items with four (4) options, A – D. The table of specification for the PEATs were prepared using Bloom's taxonomy of educational objectives as shown below:

Table 3: Table of specifications for population ecology achievement test (PEAT).

Content	Cognitive Domain						
	Knowledge	**Comprehension**	**Application**	**Analysis**	**Synthesis**	**Evaluation**	**Total**
Population Ecology	2	2	2	----	----	----	6
Succession	2	2	1	1	----	----	6
Overcrowding	2	2	1	----	1	----	6
Competition	2	2	1	1	----	1	7
Total	**8**	**8**	**5**	**2**	**1**	**1**	**25**

Validation of Research Instruments The validity of TIGEP was confirmed by an education biology lecturer at Obafemi Awolowo University, who assessed its relevance, content coverage, language use, and clarity. PERT and PEATs were deemed appropriate for SSS II students, after comparison with past WAEC questions and feedback from two biology teachers, the research supervisor, and the education biology lecturer. The fact that the instruments used were standardized examination questions by WAEC (an examination regulatory body in West Africa) gives credence to its validation. The two PEAT versions were trial-tested on 20 SSS II biology students in Osogbo (a city still in Osun State but outside the study area). The result showed internal consistency scores of 0.764 and 0.807, and a Pearson correlation of 0.778, indicating strong reliability.

Data Collection Procedure

Informed consent forms detailing the research were distributed to students with teacher guidance. Teachers were briefed on the study's significance, and students were asked for their participation. Participants' identities remained undisclosed, and lessons were scheduled conveniently to minimize risks. The experiment began two days after receiving permission and lasted two sessions per school, with a one-week interval between immediate and delayed post-tests. Participants were randomly assigned to groups, given the PERT pre-test (which served as the covariate), and given clear group-based independent instructions in Table 4 below. The conventional group was exposed to the lecture method, without prior expectancy to teach or teaching.

The researcher then taught all groups using TIGEP. At the end of the lesson, both interactive and non-interactive groups performed their assigned teacher-role activities. Others simply waited for the test. Observations were recorded on an unrestricted sheet. All participants took PEAT as post-test-1, immediately after, and post-test-2, a week later. The procedure was repeated in another school. The researcher, with extensive teaching experience, conducted all sessions to reduce variability from different teaching styles. The data collection process lasted about four weeks.

Table 4: Instructions for different conditioned groups.

Protégé conditioning group	Instruction
Learning-by-simply-preparing-to-teach group (Expectancy Group) (EG_1).	"At the end of the lesson, each one of you will teach, to your colleagues, the concept of Population Ecology as you might have understood from the lesson that will be taught to you by the researcher. Afterwards, everyone will take a test."
Learning-by-noninteractive-teaching group (EG_2).	"At the end of the lesson, each one of you will teach, without interactivity[1]*, to your colleagues

[1] *With and without interactivity was clearly explained by the researcher to the necessary participants following the operational definition of interactivity in chapter one. *Non-interactivity requires no response from tutees.

	the concept of Population Ecology as you might have understood from the lesson that will be taught to you by the researcher. Afterwards, everyone will take a test.”
Learning-by-interactive-teaching group (EG_3).	“At the end of the lesson, each one of you will teach, with interactivity*, to your colleagues the concept of Population Ecology as you might have understood from the lesson that will be taught to you by the researcher. Afterwards, everyone will take a test.”

Data Analysis Techniques

The data was analyzed using descriptive and inferential statistics. The hypotheses were tested using analysis of covariance (ANCOVA) at 0.05 level of significance, which required some preliminary analysis using scattered plots and homogeneity tests. Post-hoc analyses were done using Bonferroni’s, and specific effect sizes were estimated using Cohen’s d. All statistical analyses were performed using SPSS 29.

Results

The Average Performance of the Participants

The table below presents the average performance of the students in the pre-test, immediate (PEAT-1), and delayed tests (given a week after; PEAT-2).

Table 5: Mean and standard deviation of participants’ performance in various treatment and control groups.

Group	N	**Pre-Test**		**Post-test-1**		**Post-test-2**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Conventional Group (CG)	14	8.43	1.342	10.07	3.050	10.14	1.351
Expectancy Group (EG1)	15	8.53	1.846	12.73	3.283	11.27	2.549
Non-Interactive Teaching Group (EG2)	16	8.00	2.280	14.63	2.680	12.88	2.156
Interactive Teaching Group (EG3)	15	10.07	3.494	18.93	1.907	16.27	3.305
Total	60	8.75	2.461	14.17	4.199	12.68	3.322

Table 5 revealed that 14 (23.3%) of the participants were in CG, 15 (25%) in EG1, 16 (26.7%) in EG2, and 15 (25%) in EG3. Furthermore, Table 4 showed that the participants in CG,

EG_1, EG_2, and EG_3 had a mean score of 10.07, 12.73, 14.63, and 18 in PEAT-1. In PEAT-2, they respectively had 10.14, 11.27, 12.88, and 16.27. The standard deviations (SD) were as revealed.

The Student-Student Teaching Observation Report

Table 6: The observation of the teaching phase treatment of the non-interactive and interactive teaching group.

Non-Interactive Teaching Group EG_2	**Interactive Teaching Group EG_3**
Some students simply summarized the parts that they understood from what the teacher taught them. A few of the tutees, despite being told why their non-responsiveness and silence were vital in the non-interactive teaching phase, made certain facial gestures in agreement or disagreement with what the EG_2 students were explaining.	Many tutees, when the EG_3 students took over, eagerly asked the EG_3 students questions. Some questions were taunts, and some were for genuine clarifications. The EG_3 students answered the best that they could, independent of the main teacher. EG_3 students also used examples similar to the EG_2 students, as employed by the main teacher.
The EG_2 students used certain examples and illustrations applied by the main teacher to clarify some points.	Many tutees voiced their agreement with certain concepts that were explained by the EG_3 students.
Only a few of the EG_2 students made and answered self-generated questions. **Note:** Many students, in all experimental groups, showed eagerness to learn, as they were seen jotting down important points. There were only very few in the conventional group who did this.	Some tutees made some verbal remarks like, "So, this what he (the main teacher) meant," though this happened only with the EG_3 teacher-role students who taught well. Few tutees tried to correct perceived misconceptions, by remarking, "It's not clear," or "It's not what he (the main teacher) meant here," etc.

Hypotheses Testing

Hypothesis One: There is no significant difference in the immediate performance of students taught and tested without the protégé effect, and those taught and tested under the protégé conditioning.

To test this hypothesis, PEAT-1 scores served to measure immediate academic performance (the dependent variable), PERT scores as covariates, and the four groups of instructional strategies form the independent variable. Subsequently, a one-way analysis of covariance (ANCOVA), as in Table 7, was used to test for significant difference between the academic performance across the four groups.

Table 7: Summary of the analysis of covariance (ANCOVA) of mean scores of students taught and tested with and without protégé conditioning.

Tests of Between-Subjects Effects						
Dependent Variable: Post-Test-1 (PEAT Version 1 scores)						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	669.950[a]	4	167.487	24.871	<.001	.644
Intercept	413.499	1	413.499	61.402	<.001	.528
PERT Scores (Pre-test)	60.162	1	60.162	8.934	.004	.140
GROUP (Treatment)	494.302	3	164.767	24.467	<.001	.572
Error	370.383	55	6.734			
Total	13082.000	60				
Corrected Total	1040.333	59				

From Table 7, $F_{cal} = F_{(3,55)} = 24.47 > F_{tab} = 8.57$, $p < 0.001$ at the .05 significant level. Subsequently, the null hypothesis was rejected, indicating a significant difference in the immediate performance of the students who were taught and tested without the protégé effect, and those who were taught and tested under the protégé conditioning. Furthermore, the analysis revealed that about 57.2% (eta = 0.572) of any variance in the PEAT-1 scores is explainable by what group the participant was in (whether the participant was conditioned with mere expectancy, non-interactive teaching and interactive teaching, or was taught using the conventional method). The covariate (PERT scores with p = 0.004 at 0.05 sig. level) was also a good choice, as it could have had a significant negative effect on the ability to see the effect of the treatment, and it explains about 14% (eta of 0.14) of a participant's variance in the PEAT-1 scores.

With the detection of significant differences among the groups, a Bonferroni post-hoc analysis, as in Table 8, was further done to identify the direction of the difference in the test performance:

Table 8: Bonferroni post-hoc analysis showing the source of the significant difference in immediate performance of protégé conditioned groups.

Pairwise Comparison Dependent Variable: Post-Test-1(PEAT-1)						
(I) GROUP	**(J) GROUP**	**Mean Difference (I-J)**	**Std. Error**	**Sig.[a]**	**95% Confidence Interval for Difference**	
					Lower Bound	Upper Bound
Conventional Group (CG)	EG_1 EG_2 EG_3	-2.616 -4.739* -8.152*	.964 .952 .993	.053 <.001 <.001	-5.256 -7.344 -10.870	.023 -2.134 -5.433

Expectancy Group (EG_1)	CG EG_2 EG3	2.616 -2.123 -5.535*	.964 .936 .973	.053 .164 <.001	-.023 -4.684 -8.199	5.256 .439 -2.871
Non-Interactive Teaching Group (EG_2)	CG EG_1 EG3	4.739* 2.123 -3.412*	.952 .936 .980	<.001 .164 .006	2.134 -.439 -6.094	7.344 4.684 -.731
Interactive Teaching Group (EG_3)	CG EG_1 EG_2	8.152* 5.535* 3.412*	.993 .973 .980	<.001 <.001 .006	5.433 2.871 .731	10.870 8.199 6.094

Based on estimated marginal means

a. *The mean difference is significant at the .05 level.

As in Table 8, the mean difference between CG and EG1 is 2.616, with p =.053 at .05, a significant level. This implies that while the expectancy group performed slightly higher than the conventional group, the difference is not statistically significant. Similarly, the mean difference between the EG1 and EG2 is 2.123, with p = .164 at a .05 level. This shows that while the non-interactive teaching group performed slightly higher than the expectancy group, the difference is not statistically significant.

However, Table 8 revealed that the mean difference between the EG2 and CG is 4.739, with p <.001 at .05 significant level. This suggests that the non-interactive teaching group significantly outperformed those in the conventional group. The mean difference between EG3 and CG is 8.152, with p <.001 is at .05, a significant level. This indicates that the interactive teaching group significantly outperformed those in the conventional group. Relatedly, the mean difference between EG3 and EG1 is 5.535, with p <.001 at the .05 significant level. This means that the interactive teaching group significantly outperformed those in the expectancy group.

Furthermore, Table 8 revealed that the mean difference between EG3 and EG2 is 3.412, with p = 0.006 at .05 significant level. This indicates that the interactive teaching group significantly outperformed those in the non-interactive teaching group. Overall, it can be concluded that while participants in the expectancy group did not significantly outperform those in the conventional group, and that no significant difference in the immediate performance between the non-interactive group and the expectancy group was found, the study showed that those in the non-interactive teaching group significantly outperformed participants in the conventional group.

Additionally, Table 8 revealed that the interactive teaching group had the highest mean score and significant mean difference, when compared to all other groups. This indicates that students subjected to the protégé effect (teacher-role students), and allowed to teach others interactively, had the best performance among all the groups. However, the mean difference used here is not standardized. To make a better estimate of the effect size between interactive and non-interactive teaching groups, the standardized Cohen's d value for the two groups was calculated below:

Table 9: Summary of the effect size between non-interactive and interactive teaching groups in post-test-1.

Group	**Mean**	**σ**	**Mean Diff.**	**Cohen's d**	**Effect Size**
Non-Interactive Teaching Group Interactive Teaching Group	14.63 18.93	2.680 1.907	4.30	1.849	Large

As presented in Table 9, Cohen's d = 1.849, indicating that the effect size on immediate test performance between the interactive and non-interactive groups is relatively large.

Hypothesis Two: There is no significant difference in the performance of all the conditioned students and those without the protégé conditioning after a period of time.

To test this hypothesis, PEAT-2 scores measured academic performance on the delayed test, PERT scores as covariates, and the four groups of instructional strategies as the independent variable. Subsequently, a one-way ANCOVA, as in Table 10, was used to test for significant difference in delayed academic performance across groups:

Table 10: Summary of analysis of covariance (ANCOVA) of mean scores of students taught and tested with and without protégé conditioning after a period of time.

Tests of Between-Subjects Effects						
Dependent Variable: Post-Test-2						
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Corrected Model	404.261[a]	4	101.065	22.530	<.001	.621
Intercept	217.840	1	217.840	48.562	<.001	.469
PERTSCORES (Pre-test)	**90.609**	**1**	**90.609**	**20.199**	**<.001**	**.269**
GROUP (Treatment)	**218.634**	**3**	**72.878**	**16.246**	**<.001**	**.470**
Error	246.722	55	4.486			
Total	10303.000	60				
Corrected Total	650.983	59				

Table 10 reveals that $F_{cal} = F_{(3,55)} = 16.25 > F_{tab} = 8.57$, $p < 0.001$ at the .05 significant level. Subsequently, the null hypothesis was rejected, indicating a significant difference in the performance of all the conditioned students and those without protégé conditioning after a period of time. Furthermore, the analysis revealed that about 47% (eta = 0.470) of any variance in the PEAT-2 scores is explainable by whether the participant was conditioned with mere expectancy, non-interactive teaching, and interactive teaching, or was taught using the conventional method.

With the detection of the significant difference, a Bonferroni post-hoc analysis, as in Table 11, was further done to identify the direction of the difference in the delayed test performance:

Table 11: Bonferroni post-hoc analysis showing the source of the significant difference in performance of protégé-conditioned groups in delayed post-test-2.

Pairwise Comparison Dependent Variable: Post-Test-2(PEAT-2)						
(I) GROUP	**(J) GROUP**	**Mean Difference (I-J)**	**Std. Error**	**Sig.[a]**	**95% Confidence Interval for Difference**	
					Lower Bound	Upper Bound
Conventional Group (CG)	EG_1	-1.215	.787	.772	-3.370	.940
	EG_2	-2.973*	.777	.002	-5.099	-.846
	EG_3	-5.279*	.809	<.001	-7.494	-3.064
Expectancy Group (EG_1)	CG	1.215	.787	.772	-.940	3.370
	EG_2	-1.758	.762	.149	-3.844	.327
	EG3	-4.064*	.801	<.001	-6.256	-1.872
Non-Interactive Teaching Group (EG_2)	CG	2.973*	.777	.002	.846	5.099
	EG_1	1.758	.762	.149	-.327	3.844
	EG3	-2.306*	.799	.033	-4.492	-.120
Interactive Teaching Group (EG_3)	CG	5.279*	.809	<.001	3.064	7.494
	EG_1	4.064*	.801	<.001	1.872	6.256
	EG_2	2.306*	.799	.033	.120	4.492

Based on estimated marginal means.

a.*The mean difference is significant at the .05 level.

As in Table 11, the mean difference between CG and EG_1 was 1.215 with $p = 0.772$ at the .05 significant level. This indicates that while participants in the expectancy group slightly performed higher than those in the conventional group on the delayed test, the difference is not statistically significant. Relatedly, the mean difference between EG_2 and EG_1 is 1.758 with $p = 0.149$ at a .05 significant level. This implies that while those in the non-interactive teaching group performed slightly higher than those in the expectancy group in the delayed test, the difference is not statistically significant.

However, Table 11 revealed that the mean difference between EG_2 and CG is 2.973 with $p = 0.002$ at .05 significant level. This denotes that on the delayed test, the non-interactive teaching group significantly outperformed those in the conventional group. Similarly, the mean difference between EG_3 and CG is 5.279, with $p < .001$ at the .05 significant level. This shows that the interactive teaching group significantly outperformed those in the conventional group. The same goes for EG_3 versus EG_1, and EG_3 versus EG_2, as well, where the mean difference is 4.064 and 2.306, with a respective $p < .001$ and $p = .033$ at the .05 significant level in favour of the interactive teaching group.

With that, Table 11 reveals that the interactive teaching group had the highest mean score with statistical significance, when compared to all other groups. This further signifies that students subjected to the protégé effect (teacher-role students), and allowed to teach others interactively, had the best performance among all the groups on the delayed test, like in the immediate test. Subsequently, this means that interactivity during the student-student teaching phase of the protégé conditioning process contributes to long-term retention of biology concepts. The effect size of the contribution of interactivity was estimated by comparing the interactive and non-interactive group in Table 12 below.

Table 12: Summary of the effect size between non-interactive and interactive teaching groups in delayed test (Post-test-2 or PEAT-2).

Group	**Mean**	**σ**	**Mean Diff**	**Cohen's d**	**Effect Size**
Non-Interactive Teaching Group	12.88	2.156	3.39	1.215	Large
Interactive Teaching Group	16.27	3.305			

As shown in Table 12, Cohen's d = 1.215, depicts a relatively large effect size on delayed test performance between the interactive and non-interactive teaching groups. This further indicates that the contribution of interactivity to long-term retention is relatively large.

Discussions and Implications of Findings

The result of hypothesis one revealed a significant difference in the immediate performance of participants taught and tested without the protégé effect, compared to those who were taught and tested under protégé conditioning. This finding further indicates that the difference in participants' immediate performance can be attributed to variations in the intervention strategies to which they were exposed. However, contrary to Fiorella and Mayer (2013a), the expectancy group did not significantly outperform the conventional group in an immediate test. This minute difference in results could be explained by the fact that the participants in Fiorella and Mayer's (2013) study were not taught the concept of the Doppler effect by an actual teacher. Instead, they were required to self-study the material. Individual preferences for self-study and the differences in conditions between a simulated setting, coupled with an actual classroom environment may account for this variation in results.

Nevertheless, consistent with Fiorella and Mayer (2013), the non-interactive group outperformed the conventional group significantly on both short-term and long-term tests. Similarly, while a noteworthy improvement existed in the immediate performance of the non-interactive teaching group over the conventional group, the non-interactive group, surprisingly, did not significantly outperform the expectancy group in immediate tests. On the other hand, the interactive teaching group markedly outperformed all other groups, including the non-interactive teaching group, with a relatively large effect size. This outcome suggests that the increase in performance, via protégé conditioning in an immediate test, is influenced by the degree of interactivity between the tutees and the teacher-role students (those who teach after expecting to teach). This finding aligns with Kobayashi (2018), but contrasts with Hoogerheide et al. (2014), who argued that it does not matter whether an individual actually teaches. The difference in results could be attributed to the fact that Hoogerheide et al. (2014) conducted their study in a highly controlled laboratory setting, whereas this current study took place in an actual classroom.

Another finding from this research, addressing hypothesis two, revealed a significant difference in the performance of all conditioned students, compared to those without protégé conditioning after a period of time. This difference in delayed performance suggests that the influence of the protégé effect on academic performance extends beyond a simple novelty effect and endures over the long term. Considering the large effect size in Table 11, the interactivity between teacher-role students and their tutees has a greater impact on long-term retention than any other factor. Additionally, while the mean difference between the expectancy and non-interactive groups is not statistically significant, two subtle observations emerged. First, while the expectancy group experienced only minor gains in their mean scores compared to the conventional group, the non-interactive group significantly outperformed the conventional group in both tests. Second, although statistically insignificant, the non-interactive teaching group still achieved a higher mean score than the expectancy group.

These findings indicate that while the mere expectancy to teach contributes minimally to effortful learning—by enhancing cognitive processing and motivation (see Table 5)—actual teaching, as demonstrated in the non-interactive teaching group, amplifies these benefits to a level significant enough to outperform students who merely expect to be tested (the conventional group). This conclusion aligns with discussions from Fiorella and Mayer (2013), but continues to contrast with Hoogerheide et al. (2014), whose study relied on an overly controlled laboratory environment. Other reports supporting the learning benefits of expectancy to teach over conventional learning include classical studies by Bargh and Schul (1980), Benware and Deci (1984), Nestjoko (2014), Hoogerheide et al. (2016), Duran (2016), and Hoogerheide et al. (2016).

Furthermore, the observed minimal contribution of expectancy to learn could be attributed to how it stimulates conditioned students' attention and motivation in class. This was evident in the eagerness to master the material, which was displayed by all experimental groups (see Table 5). This motivation may stem from the fact that students expecting, or preparing, to teach paid closer attention to key points, examples, and illustrations that facilitated their understanding of what the main teacher (the researcher) taught them. A similar phenomenon was observed in the non-interactive and interactive teaching groups (see Table 5), where both groups utilized the extraneous examples provided by the main teacher to clarify concepts for their respective tutees, whether non-responsive or responsive. This phenomenon is also likely consistent for the expectancy group, as evidenced by the facial expressions of agreement observed among tutees during the teaching phase.

This observation suggests that while the main teacher (the researcher) was teaching the conditioned students, the teacher-role students actively organized information in ways that would facilitate their teaching of the tutees. This process, referred to in this study as cognitive priming for explanation, may explain the minimal learning benefits observed in the expectancy group. To elaborate, this study draws on Wittrock's (1974) generative learning theory, as utilized by Fiorella and Mayer (2013, 2014, 2015a, 2015b). According to this theory, learners construct meaning by actively comparing new knowledge with prior knowledge, thereby making sense of new information (Savannah, 2020). Through this process, learners engage in deep cognitive mechanisms, such as organizing and mentally representing concepts in coherent structures that they can comprehend, and later explain to their tutees (Mayer & Wittrock, 2006; Mayer, 2002; Wittrock, 1989). The additional act of teaching further strengthens this cognitive priming, leading to persistence in mental representation, as seen in the higher scores of the non-interactive and interactive teaching groups, as compared to the expectancy group, even in the long term (see Table 5).

The type of teaching further differentiates the results. According to the generative processing view of generative learning theory, non-interactive teaching goes beyond retrieval practice (Fiorella & Mayer, 2016a). This is because the act of explaining serves a consolidating function (Waldeyer et al., 2020) and triggers inferential processes that promote higher generative processing (Savannah, 2020). Consequently, cognitive priming for explanation is further solidified through actual teaching. However, in non-interactive teaching, this consolidation process is limited, because teacher-role students do not receive feedback from their tutees. In contrast, in the interactive teaching group, teacher-role students, actively received feedback about the effectiveness of their explanations. Positive feedback (e.g., "Oh, okay, we get it now," or "So, that's what the teacher meant here.") likely reinforced the teacher-role students' ability to integrate chosen examples into their knowledge as schemata for retrieving key concepts, whether for tests or future application.

This consolidation and integration process likely explains why interactivity augments both the short-term and long-term learning benefits of the protégé effect. Therefore, unlike Fiorella and Mayer (2014, 2015, 2016), who suggested that interactive teacher-role students learn solely by integrating selected and organized knowledge into existing schemata, this study emphasizes the critical role of consolidation. The learning process for interactive teacher-role students is thus proposed to involve three stages:

a. **Cognitive Priming for Explanation**: Students actively gather and sort information from the main teacher to understand and explain concepts to their tutees.
b. **Consolidation**: Students use feedback from their tutees to validate or revise examples and illustrations. Positive feedback reinforces the examples, while negative feedback prompts revision or removal.
c. **Integration**: Students merge the validated examples into their knowledge, forming schemata for future retrieval and application.

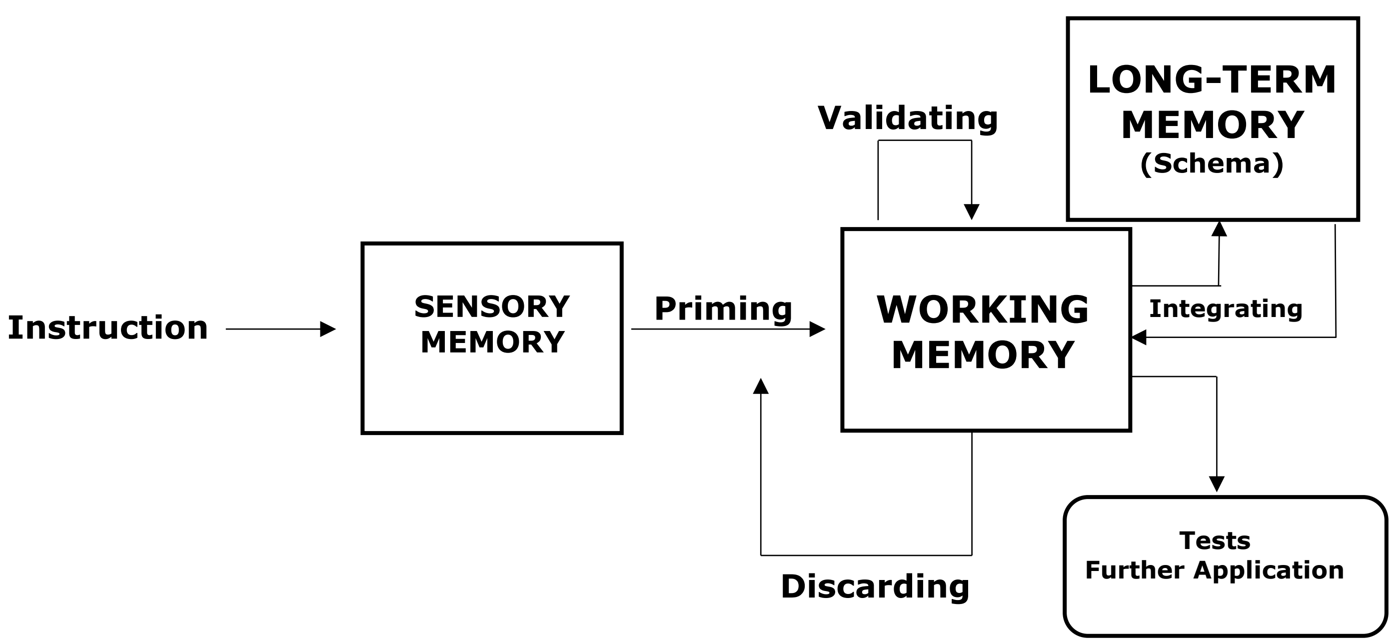

Figure 1: The CCI Model of Interactive Teaching.

To further buttress the findings of this research, different studies give credence to the importance of interactive teaching strategies towards the improvement of biology students' learning and retention. Student performance was enhanced by peer-led seminars, especially for female and under-represented minority students, as shown by Preszler (2009). Under-represented minority students in geoscience were more likely to be recruited and retained, when undergraduate teaching assistants felt accountable as role models, which is a phenomenon known as the protégé effect (Gates, 2019). This shows that there is a tendency for marked overall improvement in performance, which may cut across all learners, hence catering to all types of learners, without bias. Interactive methods that promote critical thinking and long-term memory of biological concepts include practical experiments, group discussions, and technology-enhanced learning (Akhmadkulovna, 2024). Virtual environments and interactive teaching techniques have been shown to improve learning and retention of information (Ibrahim & Al-Shara, 2007). When taken as a whole, these research findings show that interactive biology teaching methods enhance student engagement, test scores, retention rates, and the growth of critical thinking abilities. Teachers are urged to use these strategies in order to create more dynamic learning environments and satisfy the needs of students in the twenty-first century.

Conclusion

Following the aims, this study concluded that the protégé effect significantly influenced the immediate performance and long-term retention of biology concepts. This performance-enhancing ability of the protégé effect transcends that of conventional teaching methods. However, the mere expectancy to teach cannot sufficiently drive a significant increase in academic performance or retention.

Rather, interactivity is vital, especially in the long-term, because interactive teacher-role students utilize three different thought processes to internalize concepts that they learn from their main teachers. At the early stage, common to both expectancy and non-interactive groups as well, interactive teacher-role students use cognitive priming for the explanation process in order to select examples that ease teaching their tutees. With positive and negative feedback, they consolidate, or discard, these primed examples. After teaching, they integrate their amalgamated examples into their memories as schemata for aiding retrieval for tests or future applications. This indicates that incorporating interactivity through the protégé effect can effectively enhance learners' understanding, abilities, and retention for future applications. Interactivity may serve as a crucial reinforcement for both present and future learning. Additionally, it could act as a catalyst for fostering scientifically inclined learners who can adapt their current knowledge to address future environmental challenges, given the strategy's impact on retention. This has significant implications for refining teaching methods in biology to ensure inclusive, committed, and transformative learning. It also highlights the need to motivate both learners and facilitators to adopt inclusive and innovative approaches that promote effective learning. Oginni et al. (2024) explained that the students who were taught and tested under protégé conditioning performed better than those who were not, with interactivity playing a crucial role in improving retention and understanding of concepts over the long term. Also, Kobayashi (2019) showed that interactivity during the student-student teaching phase emerged as a critical factor, contributing to the effectiveness of the protégé effect, as it tends to promote multifaceted engagement, and the ability to fully explore and reinforce the material. This shows the importance of integrating interactivity into the teaching and learning processes. By incorporating peer-teaching activities into biology curricula, students are encouraged to adopt both teaching and questioning roles, so that educators can promote better long-term retention of concepts and reduce the reliance on rote memorization.

Contributions to Knowledge

This study contributes to the understanding of the protégé effect and its role in long-term retention of concepts through several key points:

a. It links the learning benefits of the protégé effect to the need for higher- knowledge precision in biology, offering solutions to improve performance in standardized biology exams, particularly in Nigeria.
b. Unlike previous studies, this research distinguishes the learning effects on both short-term and long-term scales, suggesting that consolidation might explain the minimal gains seen in non-interactive teaching groups when compared to expectancy groups.
c. It proposes reasons why interactivity is crucial for maximizing the learning benefits of the protégé effect, building on findings from earlier studies.
d. This study offers practical recommendations for teachers to apply the protégé effect in classrooms, addressing challenges like curriculum overload and time constraints. Unlike prior research, this research was conducted in a real classroom setting, closely replicating normal classroom conditions.

Limitations and Suggestions for Further Studies

The current study did not compare the effects of teacher-related factors, such as self-efficacy and pedagogical knowledge, nor did it assess students' educational and family backgrounds, interest levels in teaching, or learning characteristics on the influence of the protégé effect. These variables could potentially interact with the protégé effect's retention-enhancing ability in a full classroom setting. Additionally, demographic factors like students' gender and school type were not evaluated. Further research could explore:

a. Examining the variability of the protégé effect's benefits based on school type, considering potential differences between public and private schools.
b. Investigating how the learning benefits of the protégé effect vary between genders, as both males and females were equally represented in this study.
c. Replicating similar studies using different biology topics, or science concepts, in various regions, expanding the generalizability of the findings.
d. Assessing the impact of teachers' professional qualities, such as self-efficacy and qualification, on the benefits of the protégé effect for short and long-term retention.
e. Exploring how students' interest in teaching influences the benefits of the protégé effect on long-term retention, distinguishing between interest in teaching as a profession, and interest in the act of teaching itself.

Recommendations

a. Teachers should integrate pre-planned, student-led teaching sessions into their classrooms, especially during revision weeks, to enhance learning. Students can teach each other assigned topics, promoting both short and long-term retention. Regular reshuffling of teacher-role students can increase the number of long-term learners over time.

b. Teachers can introduce scoring systems during student-led teaching phases to reinforce the importance of these sessions and provide formative assessment opportunities.
c. Schools should conduct training sessions for senior, secondary-school students on effective teaching techniques, not to train them as professional teachers, but to enhance their ability to select and organize teaching content and build better interactivity with their peers.
d. Curriculum developers and syllabus planners should include student-led teaching activities as part of classroom practices to achieve and evaluate pre-set behavioural objectives, prompting modifications in scheme of works and lesson plans.
e. Government and educational stakeholders should incentivize teachers with better pay and remuneration to encourage the adoption of effective teaching strategies, reducing reliance on traditional lecture methods and improving performance in standardized biology examinations.
f. Teacher-training institutes and universities can integrate protégé-based microteaching sessions into their curriculum to provide teachers with practical experiences in managing student-led classroom sessions, monitoring interactions, and formatively assessing students.

Authors' Bio

Bello Malik is a first-class graduate from the department of Science and Technology Education at Obafemi Awolowo University in Nigeria. He is a seasoned researcher, with a passion for research in science education, curriculum studies, teaching, and learning.

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References

Ahmed, H. G. (2020). The role of multimedia in enhancing the teaching and learning process in Nigeria: A necessity for reforming education in Nigeria. *International Journal of Contemporary Education Research*, 158-165.

Akhmadkulovna, E. N. (2024). Enhancing biology education: The integral role of interactive teaching methods. *International Journal of Advance Scientific Research*, *4*(2), 113–121. https://doi.org/10.37547/ijasr-04-02-18

Annis, L. F. (1983). The processes and effects of peer tutoring. Human Learning. *Journal of Practical Research and Applications*, *2*(1), 39–47.

Bailon, A. (2023, March 6). *Is rote learning still effective? | SC training (formerly EdApp): The mobile LMS*. Training.safetyculture.com. https://www.edapp.com/blog/rote-learning/amp/

Bargh, J. A., & Schul, Y. (1980). On the cognitive effects of teaching. *Journal of Educational Psychology*, *72*, 593–604.

Benware, C. A., & Deci, E. L. (1984). Quality of learning with an active versus passive motivational set. *American Educational Research Journal*, *21*(4), 755–765. https://doi.org/10.3102/00028312021004755

Binks, S. (2018). Testing enhances learning: A review of the literature. *Journal of Professional Nursing*, *34*(3), 205–210. https://doi.org/10.1016/j.profnurs.2017.08.008

Bowman-Perrott, L., Davis, H., Vannest, K., Williams, L., Greenwood, C., Parker, R., & Anderson, C. (2013). Academic benefits of peer tutoring: A meta-analytic review of single-case research. *School Psychology Review, 42*(1), 39–55. https://doi.org/10.1080/02796015.2013.12087490

Chamany, K., Allen, D., & Tanner, K. (2008). Making biology learning relevant to students: Integrating people, history, and context into college biology teaching. *CBE—Life Sciences Education*, *7*(3), 267–278. https://doi.org/10.1187/cbe.08-06-0029

Chew, S. L., & Cerbin, W. J. (2020). The cognitive challenges of effective teaching. *The Journal of Economic Education*, *52*(1), 17–40. https://doi.org/10.1080/00220485.2020.1845266

Coleman, E. B., Brown, A. L., & Rivkin, I. D. (1997). The effect of instructional explanations on learning from scientific texts. *Journal of the Learning Sciences*, *6*(4), 347–365. https://doi.org/10.1207/s15327809jls0604_1

Coxon, C. H., Longstaff, C., & Burns, C. (2019). Applying the science of measurement to biology: Why bother? *PLOS Biology, 17*(6), Article e3000338. https://doi.org/10.1371/journal.pbio.3000338

Curcio, H. (2024). What is a Socratic education? In B. A. Geier (Ed.), *The Palgrave handbook of educational thinkers* (pp. 1-20). Palgrave Macmillan. https://doi.org/10.1007/978-3-031-25134-4_16

Daou, M., Buchanan, T. L., Lindsey, K. R., Lohse, K. R., & Miller, M. W. (2016). Expecting to teach enhances learning: Evidence from a motor learning paradigm. *Journal of Motor Learning and Development*, *4*(2), 197–207. https://doi.org/10.1123/jmld.2015-0036

Davis, B., & Francis, K. (2023). Discourses on learning in education: Making sense of a landscape difference, 6: 760867. https://doi.org/10.3389/feduc.2021.760867

Dinerstein, R. D. (2011, December 15). There are limitations to the Socratic method. *The New York Times*. https://www.nytimes.com/roomfordebate/2011/12/15/rethinking-how-the-law-is-taught/there-are-limitations-to-the-socratic-method

Dunlosky, J., Rawson, K., & Willingham, D. (2013). Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology. *Psychological Science in the Public Interest*, *14*(1), 4–58. https://doi.org/10.1177/1529100612453266

Duran, D. (2016). Learning-by-teaching. Evidence and implications as a pedagogical mechanism. *Innovations in Education and Teaching International*, *54*(5), 476–484. https://doi.org/10.1080/14703297.2016.1156011

Federal Republic of Nigeria. (2014). *National policy on education*. Federal Republic Of Nigeria.

Fiorella, L., & Mayer, R. E. (2013). The relative benefits of learning by teaching and teaching expectancy. *Contemporary Educational Psychology*, *38*(4), 281–288. https://doi.org/10.1016/j.cedpsych.2013.06.001

Fiorella, L., & Mayer, R. E. (2014). Role of expectations and explanations in learning by teaching. *Contemporary Educational Psychology*, *39*(2), 75–85. https://doi.org/10.1016/j.cedpsych.2014.01.001

Fiorella, L., & Mayer, R. E. (2015a). Eight ways to promote generative learning. *Educational Psychology Review*, *28*(4), 717–741. https://doi.org/10.1007/s10648-015-9348-9

Fiorella, L., & Mayer, R. E. (2015b). *Learning as a generative activity: Eight learning strategies that promote understanding*. Cambridge University Press.

Funmilayo D. F., & Adedayo O. J. (2019). The Impact of passive and active teaching methods on students' learning among secondary school students in Yenagoa, Bayelsa State. *Journal of Physics: Conference Series*, *1378*(2), 022099. https://doi.org/10.1088/1742-6596/1378/2/022099

Gates, A. (2019). The protégé effect in the retention of underrepresented minority undergraduate teaching assistants in geoscience: Preliminary indications from Newark, New Jersey. *Journal of Geoscience Education*, *67*(4), 417–426. https://doi.org/10.1080/10899995.2019.1661760

Gilbert, S. F., & Fausto-Sterling, A. (2003). Educating for social responsibility: changing the syllabus of developmental biology. *PubMed*, *47*(2-3), 237–244.

Gilbert, S. F., & Hadfield, M. G. (2022). Symbiosis of disciplines: How can developmental biologists join conservationists in sustaining and restoring Earth's biodiversity? *Development, 149*(13), Article dev199960. https://doi.org/10.1242/dev.199960

Goossens, N. A. M. C., Camp, G., Verkoeijen, P. P. J. L., Tabbers, H. K., Bouwmeester, S., & Zwaan, R. A. (2016). Distributed Practice and Retrieval Practice in Primary School Vocabulary Learning: A Multi-classroom Study. *Applied Cognitive Psychology*, *30*(5), 700–712. https://doi.org/10.1002/acp.3245

Grondin, A. J. (2018). Effectiveness of the Socratic Method: A comparative analysis of the historical and modern invocations of an educational method. *Senior Theses*, 253. https://scholarcommons.sc.edu/senior_theses/253

Güneş, F. (2020). Discussions of memorization in education. *Journal of Education, Theory and Practical Research*, *6*(3), 409–418.

Harris, K. M., & McDade, T. W. (2018). The biosocial approach to human development, behavior, and health across the life course. *RSF: The Russell Sage Foundation Journal of the Social Sciences*, *4*(4), 2–26. https://doi.org/10.7758/rsf.2018.4.4.01

Hoogerheide, V., Deijkers, L., Loyens, S. M. M., Heijltjes, A., & van Gog, T. (2016). Gaining from explaining: Learning improves from explaining to fictitious others on video, not from writing to them. *Contemporary Educational Psychology*, *45 (1)*, 95–106. https://doi.org/10.1016/j.cedpsych.2016.02.005

Hoogerheide, V., Loyens, S. M. M., & van Gog, T. (2014). Effects of creating video-based modeling examples on learning and transfer. *Learning and Instruction*, *33 (1)*, 108–119. https://doi.org/10.1016/j.learninstruc.2014.04.005

Ibrahim, M., & Al-Shara, O. (2007). Impact of interactive learning on knowledge retention. *Lecture Notes in Computer Science*, *4558*, 347–355. https://doi.org/10.1007/978-3-540-73354-6_38

Ishartono, N., Nurcahyo, A., & Dwi Setyono, I. (2019). Guided discovery: an alternative teaching method to reduce students' rote learning behavior in studying geometric transformation. *Journal of Physics: Conference Series*, *1265*(1), 012019. https://doi.org/10.1088/1742-6596/1265/1/012019

Klemm, W. R. (2007). What good is learning if you don't remember it? *The Journal of Effective Teaching*, *7*(1), 61–73.

Kobayashi, K. (2018). Learning by preparing-to-teach and teaching: A meta-analysis. *Japanese Psychological Research*, 61 (3), 192 – 203. https://doi.org/10.1111/jpr.12221

Koh, A. W. L., Lee, S. C., & Lim, S. W. H. (2018). The learning benefits of teaching: A retrieval practice hypothesis. *Applied Cognitive Psychology*, *32*(3), 401–410. https://doi.org/10.1002/acp.3410

Kotee, T., & Nguyen, C. (2021, July 16). *Instruction vs. discovery learning | AACSB*. Www.aacsb.edu. https://www.aacsb.edu/insights/articles/2021/07/instruction-vs-discovery-learning-in-the-business-classroom

Kozanitis, A., & Nenciovici, L. (2023). Effect of active learning versus traditional lecturing on the learning achievement of college students in humanities and social sciences: A meta-analysis. *Higher Education, 86*, 1377–1394. https://doi.org/10.1007/s10734-022-00977-8

Lai, Y. (2023). The double effects of standardized testing on students and environment. *Journal of Education, Humanities and Social Sciences, 8*, 1615-1620.

Landøy, A., Popa, D., & Repanovici, A. (2019). Teaching learning methods. In *Collaboration in Designing a Pedagogical Approach in Information Literacy*. Springer Texts in Education. *Springer, Cham*. 137–161. https://doi.org/10.1007/978-3-030-34258-6_10

Lin, K. P. (2024). Taiwanese teachers' beliefs toward EFL learner autonomy and their practices in high school. *Journal of Modern Education Research, 3*, Article 10. https://doi.org/10.53964/jmer.2024010

Loughlin, C., & Lindberg-Sand, Å. (2023). The use of lectures: Effective pedagogy or seeds scattered on the wind? *Higher Education, 85*, 283–299. https://doi.org/10.1007/s10734-022-00833-9

Maheshwari, V.K. (2013, August 1). *Expository teaching – A direct instructional strategy | Dr. V.K. Maheshwari, Ph.D.* Philosophical Commentary on Issues of Today. http://www.vkmaheshwari.com/WP/?p=928

Matsuda, N., Yarzebinski, E., Keiser, V., Rohan Raizada, Stylianides, G. J., & Koedinger, K. R. (2013). Studying the effect of a competitive game show in a learning by teaching environment. *International Journal of Artificial Intelligence in Education*, *23*(1-4), 1–21. https://doi.org/10.1007/s40593-013-0009-1

Mayer, R. E. (2002). Rote versus meaningful learning. *Theory into Practice*, *41*(4), 226–232. https://doi.org/10.1207/s15430421tip4104_4

Mayer, R. E., & Wittrock, M. C. (2006). Problem solving. In P. Alexander, P. Winne, & G. Phye (Eds.), *Handbook of educational psychology* (pp. 287-303). Erlbaum.

Mesfin, B. A., & Adimasu, A. A. (2020). Enhancing students' participation in classroom group discussions: An action research project on university students. *International Journal of Scientific and Research Publications, 10*(9), 829-843.

Mintz, A. I. (2018). The Socratic method: Plato's legacy in pedagogy. In *Plato* (pp. 1-10). Springer, Cham. https://doi.org/10.1007/978-3-319-75898-5_5

Moemeke, C. D. (2019). 21st century learning technologies use in Nigerian classrooms: Issues, prospects, and challenges. In *ADECT 2019 Proceedings* (p. 7).

Nasution, W. N. (2020). Expository learning strategy: Definition, goal, profit, and procedure. *IOSR Journal of Humanities and Social Science, 25*(5), 7-10. https://doi.org/10.9790/0837-2505080710

Oginni, A. M., Saibu, S. O., AWOBODU, V. Y., & Olude, A. S. (2024). Exploring the effectiveness of two tiers system of instruction on students' academic performance in basic science. *International Journal of Research and Scientific Innovation*, *X*(XII), 350–358. https://doi.org/10.51244/ijrsi.2023.1012028

Omiko, A. (2016). An evaluation of classroom experiences of basic science teachers in secondary schools in Ebonyi State of Nigeria. British Journal of Education, 54(1), 64-76.

Oyler, D. R., & Romanelli, F. (2014). The fact of ignorance revisiting the Socratic method as a tool for teaching critical thinking. *American Journal of Pharmaceutical Education*, *78*(7), 144. https://doi.org/10.5688/ajpe787144

Preszler, R. W. (2009). Replacing lecture with peer-led workshops improves student learning. *CBE—Life Sciences Education*, *8*(3), 182–192. https://doi.org/10.1187/cbe.09-01-0002

Raji, R. A. (2017). *Sequential teaching model with enhanced cognitive entry characteristics as strategy for improving learning outcomes in ecology among secondary school students* (pp. 30–35) [Unpublished Ph.D Thesis], Olabisi Onabanjo University, Ago Iwoye.

Roberts, C. O., & Reamy, B. V. (2014). The Socratic method and pimping: Optimizing the use of stress and fear in instruction. *Virtual Mentor, 16*(3), 182-186.

Roediger, H. L., & Karpicke, J. D. (2006). Test-enhanced learning: Taking memory tests improves long-term retention. *Psychological Science*, *17*(3), 249–255. https://doi.org/10.1111/j.1467-9280.2006.01693.x

Roscoe, R. D., & Chi, M. T. H. (2007). Understanding tutor learning: Knowledge-building and knowledge-telling in peer tutors' explanations and questions. *Review of Educational Research*, *77*(4), 534–574. https://doi.org/10.3102/0034654307309920

Savannah, C. M. (2020). *Applying the learning-by-teaching method in a classroom* [Unpublished Ph.D Thesis].

Shekar, C. (2018). A comparative study on rote learning: Academic performance of the rote learner and non-rote learner. *International Journal of Research Culture Society*, *2*(4).

Smith, C. D., & Scarf, D. (2017). Spacing repetitions over long timescales: A review and a reconsolidation explanation. *Frontiers in Psychology, 8*, Article 962. https://doi.org/10.3389/fpsyg.2017.00962

Sokoloff, W. W. (2019). Against the Socratic Method. *Springer EBooks*, 51–68. https://doi.org/10.1007/978-3-030-23831-5_3

Topping, K. J. (2020). Peer tutoring and cooperative learning. *Oxford Research Encyclopedia of Education*. https://doi.org/10.1093/acrefore/9780190264093.013.1432

WAEC. (2014-2022). *Chief examiner's report in biology SSCE*. WAEC.

Waldeyer, J., Moning, J., Heitmann, S., Hoogerheide, V., & Roelle, J. (2020). Does learning by teaching have double-edged effects? Manuscript submitted for publication.

Wittrock, M. C. (1974). Learning as a generative process. *Educational Psychologist, 11*(2), 87–95. https://doi.org/10.1080/00461527409529129

Wittrock, M. C. (1989). Generative processes of comprehension. *Educational Psychologist*, *24*(4), 345–376. https://doi.org/10.1207/s15326985ep2404_2