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Adaptable Cognitively Guided Inquiry-Based Instructional Approach and its Impact on Students' Academic Achievement in Physics: A Quasi-Experimental Study

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Abstract. Studies have consistently attributed students' poor achievement in physics to the continued use of conventional teacher-centred instructional approaches. This study, therefore, investigated the effect of a contextually responsive, cognitively guided instructional strategy on the academic achievement of secondary school physics students in Ibadan Metropolis, Nigeria. The interaction impact of students' mathematical ability was also assessed. Grounded in theory of constructivism, the study adopted the quasi-experimental pretest-posttest control group design. The research spanned 13 weeks and involved 110 senior secondary school physics students. Validated research instruments were used for data collection, and data were analysed using multilevel linear modelling. Findings revealed that a significant impact of the intervention on the students' academic achievement, $F(1, 850.810) = 137.668$, $p < 0.001$. Further analysis indicated substantial differences in post-test mean achievement scores between students exposed cognitively guided instructional strategy and those taught with the conventional method. The study recommends the adoption of instructional contextualisation as an effective pedagogical approach for teaching physics. It also suggests further research into the interaction effects of additional learner-related variables on students' academic performance in physics.

Keywords: academic achievement; cognitively guided instruction; instructional contextualization; mathematical ability

1. Introduction

Studies on students' achievement in Physics in Nigeria have been largely driven by recurring reports from the Chief Examiners of the West African Examinations Council (WAEC), which highlight persistent deficiencies in student performance

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in the West African Senior School Certificate Examination (WASSCE) between 2013 and 2019. For example, the 2013 and 2014 reports noted that many students demonstrated a poor comprehension of essential Physics concepts and faced challenges with language comprehension (WAEC, 2013; 2014). Additionally, the 2014 report pointed out students' inability to apply acquired knowledge to real-life contexts. The 2015 report recommended that Physics teachers go beyond merely presenting laws and principles to demonstrating their practical applications in everyday situations.

It further advised that learners be encouraged to explain these principles and laws in their own words to enhance their ability to transfer learning to real-world contexts. Subsequent WAEC reports (2016, 2018) reiterated the need to discourage rote learning, promote active student engagement, and support classroom instruction with demonstrations and participatory teaching strategies (WAEC, 2016; 2018).

These issues have been widely discussed in the literature. Several studies have identified the persistent use of teacher-centred methods of instruction—such as lecture and note dictation—as a key barrier to effective Physics teaching, despite repeated calls for more learner-centred pedagogies (Bello, 2015; Aderonmu & Obafemi, 2015; Osondu, 2018). According to Starkey (2019) and Baafi (2020), the prevalence of teacher-centred approaches is often linked to factors such as limited instructional resources and the pressure to cover the curriculum efficiently. Science teachers tend to favour these methods due to their perceived effectiveness in maximizing content coverage within limited instructional time (Altinyelken & Hoeksma, 2021; Baafi, 2020). However, these strategies often overlook the impact of students' individual characteristics—such as prior informal experiences—on their learning.

Learning is a multifaceted process shaped by various factors, including learners' previous experiences and the contexts in which those experiences occur. Such experiences form a cognitive framework for interpreting new knowledge (Fung et al., 2018). Research has long proved that students' prior experiences are significant predictor of learning outcomes (Shing & Brod, 2016; van Riesen et al., 2019; Simonsmeier et al., 2021). Dong et al. (2020) emphasized that although prior knowledge is critical, its specific impact on students' learning in Physics has not been extensively explored. This gap is significant, especially considering the consensus in the literature that students' background knowledge plays a central role in shaping new learning experiences (Fung et al., 2014; van Riesen et al., 2019).

The overarching aim of this study is to contribute to the discourse on the relevance of students' prior informal learning experiences in Physics by proposing and evaluating strategies that integrate this knowledge within formal classroom instruction. To achieve this, the study adopts the Contextually Responsive Cognitively Guided Instructional Strategy (CGIS), which is grounded in constructivist principles. CGIS makes use of learners' prior experiences with informal physics to guide instruction. Originally conceptualized by Carpenter, Fennema, and Franke (1996), CGIS promotes conceptual understanding through rich classroom discourse, guided discovery, and problem-solving activities centred around core science and mathematics concepts. Rather than assuming students begin school with little to no scientific or mathematical knowledge, CGIS recognizes their pre-existing understanding as a foundation for formal learning (Carpenter et al., as cited in Munday, 2016). In a CGIS classroom, the teacher acts as a facilitator, using demonstrations, interactions, and targeted questioning to guide learners through concept development.

Given that Physics is heavily dependent on mathematical representations—such as numerical relationships and formulas—mathematical ability plays a crucial role in students' academic performance in the subject (Charles-Ogan & Okey, 2017). As such, this study also explores the interaction effect of students' mathematical ability on their academic achievement in Physics.

1.1 Objectives of the Study

The study primarily focused on achieving the following specific objectives:

1. Investigate the capability of the intervention to improve the academic achievement of physics Students'
2. Compare the effects of the instructional approaches (the intervention (CGIS) versus the teacher-centred strategy (Control)) on the academic achievement of the students.
3. Assess the possible interaction effect of mathematical ability on the students' academic achievement in physics.

2. Review of Related Literature

Relevant literature aligned with the main objectives of the study is discussed in this section. This includes the theoretical framework underpinning the study, the rationale for the research, and a review of the key variables.

2.1 Theoretical Foundation and Study Context

The study was grounded in social constructivist theory, which served as the theoretical framework guiding the research. As noted by Amineh and Davatgari (2015), social constructivism views knowledge construction as an active process wherein learners develop cognitive frameworks through interaction with their environment. The value of social constructivist theory in instructional practice lies in its emphasis on students actively internalizing and reconstructing knowledge through meaningful experiences and social engagement. Andang and Purwarno (2018) identified several key characteristics of constructivist learning, including the promotion of authentic learning in meaningful contexts, a focus on learning as a process, the integration of social interaction in learning, and the recognition of students' prior experiences as critical to their learning development.

In this study, Cognitively Guided Instructional Strategy (CGIS) is operationalised as a student-centred, guided inquiry-based approach that draws on learners' prior classroom experiences as a foundation for achieving the intended learning outcomes (Moore & Cuevas, 2022). Students' existing knowledge is used as a springboard for constructing new understanding. A core feature of CGIS is the use of story problems, which serve as a powerful tool to enhance conceptual understanding in both mathematics and science. Such narrative tasks support meaningful connections between learners' existing knowledge and new concepts (Munday, 2016). Story-based learning tasks not only foster engagement and enjoyment but also provide teachers with opportunities to detect and correct misconceptions, while allowing students to develop problem-solving strategies they find intuitive rather than imitate unfamiliar ones (Jacobs & Ambrose, 2008).

Hadzigeorgiou and Schulz (2019) argue that to deeply understand scientific ideas and concepts in physics, learners require both hands-on experiences and expert guidance. These support the integration of prior knowledge into new learning. The implementation of CGIS in the classroom, therefore, involves the deliberate use of varied learner experiences and instructional resources—referred to as advance organizers—to guide and scaffold learning. As explained by Akinbobola (2015), the use of advance organizers promotes meaningful engagement by incorporating students' existing views, facilitating clarification, communication, and reinforcing scientific principles.

In contrast, the control group was exposed to a teacher-centred instructional approach, where the teacher is the primary source of information, and learning is driven by content delivery rather than inquiry or exploration. Baeten et al. (2016) describe this model as one in which the teacher dominates instructional activities, delivering pre-prepared content through direct instruction. Learning outcomes are assessed predominantly through multiple-choice and summative assessments (van de Kuilen et al., 2019). Lessons are designed to achieve predetermined curriculum objectives, with emphasis on coverage rather than comprehension. Students typically write dictated notes and engage passively with the content. Within this framework, the teacher is perceived as the ultimate authority, directing all learning activities and providing definitive answers to students' questions. Di Biase (2019) notes that in such classrooms, the teacher exerts full control over instructional decisions, limiting student agency and interaction.

2.2 The Role of Students' Prior Informal Knowledge of Physics in Effective Physics Learning

Studies have shown that students often bring with them a wealth of informal experiences related to physics, acquired through daily life encounters outside the classroom. This informal knowledge of physics refers to unstructured, everyday experiences involving physical phenomena that are not explicitly framed within the formal, technical, and disciplinary context of school physics. For example, students may arrive at school with intuitive but often misconceived understandings of motion and momentum (El-Adawy et al., 2024). These prior experiences serve as a foundation—albeit sometimes flawed—for constructing new physics knowledge within formal classroom settings.

Informal physics knowledge encompasses students' experiential understanding developed outside the guidance of a prescribed curriculum. El-Adawy et al. (2024) define informal knowledge as that which is acquired through participation in activities, events, and engagements beyond the formal classroom environment. This understanding aligns with terms such as out-of-school experiences, everyday knowledge, or free-choice learning, all of which emphasise learner agency and real-world contexts in the development of science understanding.

The sources of informal science knowledge are diverse and include after-school programmes, public lectures, science exhibitions, festivals, open houses, social media platforms, websites, popular science books, television shows, films, and games (Hein, 2009, as cited in El-Adawy et al., 2024). For instance, learners may enter a physics classroom with a basic understanding of motion and speed—concepts derived from everyday observations of moving objects. Such informal knowledge, though often inaccurate, presents a valuable opportunity for educators to scaffold formal instruction. Concepts such as velocity and acceleration can be meaningfully introduced by building on students' pre-existing ideas about movement.

Tasar and Heron (2023) emphasize the pivotal role of informal knowledge in enhancing students' comprehension and overall academic performance. Similarly, Brunt and Brunt (2013) demonstrated how principles like the conservation of momentum can serve as conceptual anchors for teaching Newton's laws of motion. However, research by Hohensee (2016) suggests that many teachers lack sufficient understanding of the nuanced relationship between students contextualised prior knowledge and formal physics content.

This gap in pedagogical knowledge often hampers efforts to connect classroom learning with real-life experiences. Suryawati and Osman (2017) argue that contextual approaches to instruction, rooted in constructivist learning theory, are essential for bridging this divide. Such approaches stress that learning is not merely a process of memorisation, but rather one of constructing meaningful connections between classroom content and lived experiences.

As Main (2024) notes, contextualised teaching strategies aim to provide relevant, engaging, and meaningful instruction by grounding curricular content in real-world situations. This alignment with how the brain naturally processes information enhances learning outcomes by encouraging students to actively construct knowledge based on both their informal experiences and formal instruction.

2.3 Rationale for Adopting Cognitively Guided Instructional strategy (CGIS)

Students enter school with substantial informal knowledge of science, including foundational physics ideas, acquired through their everyday experiences with the natural world (Blonder & Mamlok-Naaman, 2016). However, Sarıoğlan and Küçüközer (2014) note that this informal knowledge often conflicts with the formal structures of physics taught in classrooms. Such conflicts are referred to as misconceptions, which Govender (2017) defines as conceptions that contradict scientifically accepted theories. Misconceptions are common across nearly all physics topics (Liu & Fang, 2016).

For example, many students struggle to recognize the mathematical relationships between Newton's second law, momentum, and impulse, often believing that momentum and impulse only relate to collisions (Liu & Fang, 2016). Addressing these misconceptions requires instructional approaches specifically designed to restructure students' understanding.

Research shows that Cognitively Guided Instructional Strategy (CGIS) effectively enhances students' conceptual understanding. One key advantage of CGIS is its emphasis on students articulating their reasoning and collaborating with peers, which has been linked to higher achievement in mathematics and related disciplines like physics (Webb et al., 2008). However, Fyfe et al. (2014) caution that the success of CGIS depends on the nature of the content being taught. To improve its effectiveness, the use of advanced organizers at the start of instruction is critical, as they help students connect their informal knowledge to the new lesson content (Akinbobola, 2015).

Zheng et al. (2008) describe an advanced organizer as an instructional tool introduced at the beginning of a lesson to activate students' prior experiences and facilitate comprehension by linking it to upcoming new information. Suwais and Alshahrani (2018) note that this concept was first introduced by Ausubel in the 1960s. Advanced organizers provide introductory material before the main course content (Vander Meij, 2019). Men et al. (2019) and Nisyah et al. (2020) demonstrate that advanced organizers familiarize students with new concepts, help integrate prior experiences, and connect these to the new material.

By presenting advanced organizers at the outset of learning activities, students can better organize and understand new concepts through meaningful links to existing knowledge. For example, Githua and Nyabwa (2008) found that students taught using advanced organizers scored higher on Mathematics Assessment Tests compared to those receiving conventional instruction. Furthermore, engaging students in interactive activities, discussions, and feedback facilitated by advanced organizers leads to improved academic performance relative to traditional lecture methods (Aupperlee, 2021). Effective active learning strategies involve both hands-on and minds-on techniques but also foster emotional and social support. Additionally, research suggests that learner-related factors, such as mathematical ability, can moderate and mediate the impact of instructional strategies on student achievement.

2.4 Students' Mathematical Ability

Physics heavily relies on mathematical representations, including numbers and formulas, to elucidate the interaction of various elements in the environment. Consequently, there is a strong link between mathematical ability and students' performance in Physics. Mathematical ability describes the ability of students to acquire, practice, and retain mathematical information (Ogan & Okey, 201709). This definition is corroborated by Blacksmith (2016) which described mathematical ability as the capacity to acquire and grasp new mathematical ideas and skills.

As noted by Chassy and Jones (2019), a comprehensive understanding of mathematical descriptions is essential for a profound comprehension of physics concepts. For example, the physics of a point, as described by classical mechanics, is typically articulated through a series of equations. Among these, the simplest equation relates velocity to displacement and time, often introduced early in the senior secondary school curriculum (expressed as $v = d/t$, with related derivatives such as d = vt, where d represents displacement in meters, v denotes velocity in meters per second, and t signifies time in seconds). Mastery of this basic equation hinges on a firm grasp of multiplication and division (Chassy, 2019). Charles-Ogan and Okey (2017) proposed that students' successful comprehension and application of electromagnetic concepts hinge on a robust understanding of mathematics. Thus, students' grasp of fundamental mathematical concepts significantly influences their ability to tackle higher-level mathematical ideas, crucial for advanced physics comprehension. Mathematical calculations are integral at every juncture in physics, directly impacting students' academic performance.

3. Methodology

The investigation adopted a pretest-posttest control group quasi-experimental design. This design was chosen because it involves manipulation of the independent variable while allowing for comparison between groups (Gopalan et al., 2020). In this study, the independent variable is the instructional strategy, manipulated at two levels: the treatment (intervention) group and the control group. The treatment group were exposed to CGIS, while the control group was taught using the traditional teacher-centred instructional strategy. The dependent variable is students' academic achievement in physics.

The quasi-experimental design enables the researcher to establish a hypothetical baseline representing the likely outcome without the intervention, which serves as a point of comparison for estimating the causal effects of the instructional strategies. This design incorporates non-experimental modifications of the independent variable and simulates experimental conditions by exposing some participants to the intervention while others are not, often without full randomization (Gopalan et al., 2020).).

3.1 Sample and Sampling Technique

Senior Secondary School (SSS) students were purposefully chosen for the investigation and then randomly allocated to two groups: the intervention (experimental) group and the control group. One instructional strategy was administered in each selected school. To prevent data contamination from students sharing ideas between groups, separate schools located at a distance from each other were chosen for the study. At the outset, students were informed about the nature and purpose of the research. An agreement with the school management stipulated that the study sessions would be treated as extramural classes, open to students interested in participating; however, participation was voluntary.

A total of 110 senior secondary school students from Ibadan metropolis participated, with 54 students (49.1%) in the CGIS group and 56 students (50.9%) in the control group. To ensure unbiased group assignment, a simple random sampling technique was used: numbers were drawn randomly from a container, assigning students with odd numbers to the CGIS group and even numbers to the control group. The participants' ages ranged from 14 to 17 years, with a mean age of 15.5 years. This mean age aligns with the typical age for senior secondary education in Nigeria, considering that the minimum university admission age is 18 years (Arise TV, 2024). The potential influence of students' age was treated as a contextual variable and controlled during data analysis using multilevel modelling.

3.2 School Selection Criteria
Initially, a preliminary study was conducted to assess the number of professional physics tutors in selected government-owned senior secondary schools. The willingness of the schools to participate served as a key inclusion criterion. Additionally, the preliminary investigation evaluated how far the schools had covered the K-12 physics curriculum to ensure equal degree of exposure to the relevant physics content. Consideration was also given to the availability of teaching resources, the availability of an efficient physics laboratory, and the conduciveness of the learning environment. These contextual factors were deemed important, as students exposed to better conditions might have an advantage over those in more remote or less-resourced environments.

The following criteria guided the selection of participants for the study:

- Inclusion of a public senior secondary school class that had completed one year of physics instruction and had begun mechanics topics in the second-year physics curriculum. This ensured that all participants were at a similar level of exposure to the relevant physics content, particularly topics covered in the first term of Senior Secondary Two.

- Selection of schools with conducive teaching and learning environments for physics instruction, recognizing that an unfavourable environment could negatively impact the implementation and outcomes of the study.

- Identification of schools with qualified physics teachers, based on the understanding that students taught by competent instructors are better positioned to engage with any instructional model.

Note: The extent of curriculum coverage was a critical factor in the selection process.

3.3 Engagement of Research Assistants/Teachers for the Study
The process involved an assessment procedure using participant observation to evaluate the teachers' abilities. Registered physics tutors with more than four years of professional experience were recruited, as literature indicates that teachers' experience significantly impacts students' learning outcomes (Oguta, 2022). Several studies have criticized Initial Teacher Education (ITE) programs for being overly theoretical and insufficiently preparing teachers for the practical realities of classroom teaching (Joseph, 2017). These studies suggest that the training provided by teacher education institutions does not adequately equip teachers to handle the challenges they encounter professionally. Therefore, this study specifically considered teachers with over four years of experience, as they

are likely better equipped both to implement the new instructional approach and to manage potential challenges.

From an initial group of ten candidates who participated in the training, two tutors were assigned to each experimental group, while a third tutor served in a supplementary role, including collecting data to monitor the procedural fidelity of the intervention implementation. Teacher performance during training was assessed with the Evaluation Forms for Physics Teacher's Performance (EFPTP). This instrument was designed to measure teachers' efficient execution of the instructional steps and stages tailored for both the Cognitively Guided Instruction and control groups. The evaluation criteria encompassed various professional skills (detailed in the supplementary form). Based on their training performance, three best performed teachers were selected.

Regarding demographics, two of the selected tutors were aged between 41 and 50 years, holding B.Sc. (Ed) and B.Ed degrees respectively, with 5 to 9 years of teaching experience. The third tutor was aged between 21 and 30 years, held an M.Ed degree, and had 5 to 9 years of teaching experience.

3.4 Research Instruments
The following research instruments were used for data collection:

3.4.1 Test of Physics Achievement (TPA):
The TPA was developed by the researcher to evaluate students' comprehension of the physics content covered during the intervention. The test items were carefully selected and adapted from standardized questions found in past WAEC examinations (2013–2020) (WAEC, 2020) and physics textbooks (Anyakoha, 2010). These items were aligned with the topics taught during the study and modified to suit the participants' learning levels. The development of the TPA questions was guided by the six major levels of Bloom's Taxonomy of the Cognitive Domain, as outlined in Table 2 below. The instrument included a variety of item types, such as physics word problems, definitions, descriptions, examples, characteristics of concepts, and application questions.

The TPA consisted of two sections:

Section A: Collected demographic information, including school name, gender, class, and age.

Section B: Contained 20 multiple-choice questions, each with four options (A–D), designed based on a table of specifications for selected physics topics.

The test covered topics such as Motion (including linear momentum and impulse), Mechanical Energy, and Machines, with items reflecting the specifications detailed in Table 1 below.

Table 1: Specification of Items for TPA

CONTENT	COGNITIVE LEVELS						
	KNW	**COMP**	**APP**	**AN**	**SYNT**	**EVA**	**TOT**
MOTION	^{1}(1)	^{3} (1)	^{18} (1)	$^{2, 9, 10}$(3)	^{12}(1)	$^{4, 20}$(2)	9
MECH. ENERGY	$^{5, 6}$(2)	^{11}(1)	-	-	-	^{19}(1)	4
MACHINES	$^{8, 16}$(2)	^{13} (1)	^{6}(1)	^{6}(1)	-	^{15}(1)	7
TOTAL	5	3	2	5	1	4	20

The keys represent the following cognitive levels:
KNW = Knowledge; COMP = Comprehension; APP = Application; AN = Analysis; SYNT = Synthesis; EVA = Evaluation; TOT = Total

Note: The numbers in parentheses indicate the number of items in respective cell, whilst the subscripts denote the serial numbers of the items in the TPA.

3.4.2 Students' Mathematical Ability Test (SMAT)
The Students' Mathematical Ability Test (SMAT), adapted from Galli et al. (2008), was used to assess students' numerical manipulation skills. The test consisted of two sections: the first collected demographic information such as school name, gender, class, and age, while the second contained 20 multiple-choice questions with four answer options (A–D), designed to evaluate learners' mathematical achievement. The questions were constructed based on a table of specifications aligned with selected physics topics.

3.4.3 Validity and Reliability of the Instruments
i. Test of Physics Achievement (TPA): The TPA was validated through expert review to establish face and content validity. The panel of specialist included professionals in measurement and evaluation (psychometrics), physics teachers, and science educators. Copies of the TPA were distributed to these experts to assess the quality, accuracy, language suitability, and adequacy of the items. Their feedback guided necessary revisions before trial testing. The researcher then conducted a trial test to evaluate reliability. Initially containing 50 items, the instrument was reduced to 20 questions based on item difficulty and discrimination indices. The reliability of the final instrument was determined using the Kuder-Richardson 20 (KR-20) formula, yielding a reliability coefficient of 0.78.

ii. Skills in Mathematical Ability Test (SMAT): Face and content validity for the SMAT were confirmed by specialists in mathematics education. SMAT was piloted with 50 students outside the study area. Item analysis was conducted to evaluate item difficulty and discrimination indices. Reliability was assessed using the KR-20 formula, resulting in a reliability coefficient of 0.80.

Note: Samples of the instruments are provided in the appendix.

3.4.4 Duration of the Study
The study was conducted over a full school term, with the following timeline:

- Week 1: School selection
- Week 2: Teacher training and pretest administration
- Weeks 3 to 12: Intervention implementation
- Week 13: Posttest administration
- Total duration: 13 weeks

3.5 Implementation of the Strategies
The study adapted the instructional guide designed by Okeke (2024). It is available on https://data.mendeley.com/datasets/9rdm7xr5zs/1.

3.6 Procedural fidelity
Data on teachers' performance was collected using observation sheets to assess the fidelity of the intervention implementation. Four doctoral students, serving as research assistants, observed and evaluated the teachers' adherence to the instructional procedures outlined in the guide. For each correctly implemented item, observers marked a check [√] on the observation form. The fidelity score was calculated by dividing the number of checked items by the total number of items on the form, then multiplying by 100%. This process measured the accuracy and extent of implementation.

$$\text{Procedural Fidelity Score} = \frac{\text{Number of ticked } [\surd] \text{ items}}{\text{Number of items on the Observation Sheet}} \times 100\%$$

The ratings from the observers were compiled to calculate the average fidelity scores for each interventionist. The overall average fidelity score was 94.55%, indicating that the intervention was implemented with a high level of accuracy.

3.7 Data Analysis Method
Multilevel linear model analysis was chosen because of the nested arrangement of the data. Since intact classes from selected schools were randomly assigned to the instructional strategies, this design aimed to minimize the influence of confounding variables. However, using intact classes introduces dependencies among observed cases and nesting of subjects, which can itself confound the study's outcomes. When an intact class is assigned to one level of an independent variable, the data are influenced by various factors such as environmental conditions, teacher characteristics, and student traits. This leads to hierarchical data, also known as data nesting.

In such studies, issues like interclass and intraclass correlations (ICCs) arise, reflecting the likelihood that students' outcomes are influenced by shared qualities like their tutor's effectiveness, available resources, classroom environment, and student maturity. Tabachnick and Fidell (2014) and Mertler and Reinhart (2017) explain that nesting happens once levels of an independent variable correspond to just a single level of a dependent variable — as happens once entire classes, rather than individual students, are assigned to interventions. Consequently, students' post-achievement mean scores serve as the dependent variable. The multilevel linear model was therefore employed to appropriately handle the error terms linked with random assignment of intact classes and address issues arising from unequal sample sizes across groups.

The study also incorporated a moderator variable to explore whether factors other than the instructional approach might influence differences in students' learning outcomes between groups. This aligns with Gavarkovs et al. (2024), who emphasize that while experimental comparisons of instructional approaches can demonstrate effectiveness, they often fail to reveal the underlying mechanisms of how these strategies work. To better understand these mechanisms, Gavarkovs et al. advocate for including mediation or moderation analyses in comparative studies to illuminate the processes through which instructional designs operate.

Regarding missing data, unequal group sizes can resemble an unbalanced design and introduce bias. The multilevel model's algorithm was chosen partly because of its robustness against biases caused by missing data. Instead of removing incomplete cases (listwise deletion), which is problematic in studies with small sample sizes, multilevel modelling allows for the use of incomplete data without biasing estimates under certain conditions (Raudenbush & Bryk, 2002). The data were treated as nested within instructional groups (i.e., classes), and the model estimated parameters without imputing missing values.

Two estimation methods were used in the modelling: Maximum Likelihood (ML), which is preferred for estimating fixed effects, and Restricted Maximum Likelihood (REML), which is better suited for estimating variance components (random effects). The analysis reported both fixed and random effects results. Importantly, participants' pretest (baseline) scores were included as covariates to adjust for any pre-intervention differences.

3.8 Analytical Procedure

The analytical procedure involved three stages of model development. The first stage examined the fixed effects of the intervention without including the pre-test scores as a covariate. In the second stage, the model was refined by incorporating the pre-test scores as a covariate and accounting for the hierarchical structure of the data. In the final stage, the model further incorporated random intercepts and slopes, which improved the log-likelihood and enhanced the model's ability to predict students' academic achievement.

As a result, the final model achieved a log-likelihood (-2LL) value of 646.25. Comparing this to the previous model's -2LL value of 652.15, the change in -2LL was 5.90. This corresponds to a chi-square change ($\Delta\chi^2$) of 5.90 with 1 degree of freedom, exceeding the critical chi-square value at df = 1, indicating that the final model provides a significantly better fit to the data. The earlier stages of the model assumed a Variance Components covariance structure, treating slopes and intercepts as uncorrelated. In contrast, the final stage used an Unstructured covariance structure, allowing for possible correlations between slopes and intercepts.

4. Findings

The results of the multilevel linear model analysis are presented as follows:

4.1 Impact of Intervention on Academic Achievement of the Students

The initial phase of the multilevel linear model analysis examined the intervention's impact on the academic achievement of the students. The findings are summarized in Table 2 below

Table 2: Tests of Fixed Effects

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	109	2606.656	.000
Intervention	1	109	873.256	.040

The results showed a significant predictive effect of the intervention on students' academic performance in Physics, indicated by the analytical significance ($F(1, 109) = 873.26$, $p = 0.040$). Nevertheless, this initial analysis did not account for the influence of baseline academic performance, measured by students' pretest scores (pre-achievement). To address this, a revised model was developed that included baseline achievement as a covariate. The results of this adjusted analysis are displayed below:

Table 3: Tests of Fixed Effects

Source	**Numerator df**	**Denominator df**	**F**	**Sig.**
Intercept	1	109	412.636	.000
Intervention	1	109	336.254	.000
Pre-achievement	1	109	.848	.359

The results show a significant effect of the intervention on students' achievement ($F (1, 109) = 336.254$, $p = 0.00$). However, baseline scores, measured as pre-achievement, did not have a significant impact on students' achievement ($F (1, 109) = 0.848$, $p = 0.359$). This finding highlights the fixed effect of the intervention on physics achievement, similar to an ANCOVA analysis using the Univariate General Linear Model (GLM). Notably, the intervention's coefficient had a negative value ($b = -1.46$), suggesting a detrimental effect on academic performance.

This outcome may be due to the fixed-effects model coefficients. Moreover, the model did not account for the hierarchical structure of the data, violating the assumption of independence. Students taught by the same teacher are likely to have correlated scores that differ from those of students in other classes (Field, 2018). In other words, the model did not control for potential confounding variables such as teacher quality, environmental factors, and other contextual influences, which may have affected the results.

To address these limitations and improve model fit, variability, and generalizability, random intercepts and slopes were added to the model. This adjustment accounted for the nested data structure at the class level. The updated analysis showed a difference of 5.902 in the model's Log Likelihood (-2LL), corresponding to a chi-square change ($\Delta\chi^2$) of 5.90 with 1 degree of freedom, exceeding the critical value for df = 1. This indicates a better fitting model. Detailed outcomes are displayed in Table 4

Table 4: Tests of Random Effects

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	142.008	415.348	.000
Intervention	1	850.810	137.668	.000
Pre-achievement	1	115.865	.036	.850

The results reveal a significant of the intervention on the academic achievement of the students in Physics, as indicated by $F(1, 850.810) = 137.668$, $p = 0.000$. In contrast, students' baseline scores (Pre-Achievement) showed no significant impact on academic achievement, with $F(1, 115.865) = 0.036$, $p = 0.850$.

Significant variation in intercepts among participants was observed in the relationship between the intervention and students' academic achievement, as shown by $Var(u0j) = 1.29$, $\chi^2(1) = 3.80$, $p < 0.01$. Additionally, variation in slopes was found, with $Var(u1j) = 1.27$, $p < 0.01$, along with a negative covariance between slopes and intercepts, $Cov(u0j, u1j) = -1.32$. Although these slopes and intercept values are unstandardized and not the focus, the negative covariance suggests variability in the quality of learning outcomes across different groups. Overall, the findings emphasize that the intervention significantly predicted students' academic achievement, as supported by $F(1, 850.810) = 137.668$, $p = 0.000$.

4.2 Comparative Evaluation of the Impact of the Instructional Approaches on the Academic Achievement of the Students in Physics

Analysis of the data in Table 5 indicates that students in the CGIS group attained the highest average post-test scores measuring academic performance in Physics across all classes.

Table 5: Statistics Showing the Mean Scores of Students' achievement in Physics Pre-test and Post-test Exercises

Performance	Intervention	No. of Students	Mean
Pre-test	Cognitively Guided Instructional Strategy	54	4.71
	Conventional Instructional Strategy (CIS)	56	4.45
Post-test	Cognitively Guided Instructional Strategy	54	13.53
	Conventional Instructional Strategy (CIS)	56	9.21

The observed variation in students' academic achievement across the two instructional groups can be credited to the efficiency of the instructional strategies adopted for the study. This conclusion is strengthened by the analytical approach, which accounted for contextual factors such as teacher quality, teachers' professional experience, classroom dynamics, and environmental influences. These contextual variables were modelled as part of the data's nested structure and appropriately controlled for in the analysis. Recognizing that students' mathematical ability may also affect their academic achievement in Physics, the study further examined both the main and interaction effects of mathematical ability.

4.3 The Possible Impact of Mathematical Ability on Students' Academic Achievement in Physics

The effects and interaction of mathematical ability were incorporated into the model, with the results detailed below.

Table 6: The impact and interaction effect of mathematical ability

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	65.51	32.590	.000
Intervention	1	52.76	.618	.65
Pre-achievement	1	99.92	.038	.072
Mathematics Ability	1	92.67	.051	.822
Intervention*Mathematics Ability	1	98.34	.111	.739

The findings, as presented in Table 6, show no significant main or interaction effects of mathematical ability on students' academic achievement in physics.

5. Discussion of Findings

The findings of this study, as presented in Tables 2, 3, and 4, demonstrate a significant main effect of the intervention on students' academic achievement, indicating an overall improvement. However, at this stage, the study cannot conclusively determine which instructional strategy is primarily responsible for the observed gains. This is because any instructional interaction between teacher and students is generally expected to yield some level of improvement, however slight. Thus, despite criticisms, the teacher-centred approach also has the potential to enhance students' academic achievement. This supports Baeten et al.'s (2016) position that teacher-centred strategies can effectively achieve desired learning objectives since these objectives are designed and implemented by the teacher.

To identify the instructional strategy with the most significant impact on academic achievement, further analysis was conducted. This revealed a notable difference in mean post-test scores between students exposed to the Cognitively Guided Instructional Strategy (CGIS) and those taught via the Conventional Strategy (CS). The CGIS group achieved a higher average estimated mean score of 13.53, compared to 9.21 for the CS group, underscoring the superior performance of students in the CGIS group across the participating schools. This result highlights the effectiveness of CGIS relative to conventional methods, corroborated by previous studies such as Schoen et al. (2020, 2022).

Closer examination of school-level data showed consistent outperformance by students in the intervention group, aligning with constructivist theory, which emphasizes students' active role in constructing knowledge. Andang and Purwarno (2018) note that constructivism prioritizes authentic, student-driven learning, where students bear responsibility for their learning outcomes. Kong (2021) similarly underscores learner-centred pedagogy as central to educational innovation due to its focus on developing students' abilities and experiences. Under this framework, learning is not simply knowledge transfer, but an active construction facilitated by structured engagement with the teacher (Che et al., 2021).

The success of CGIS can be attributed to its emphasis on active student involvement, thorough conceptual explanations, and collaborative teacher-student interactions. Effective learning occurs through experiential and experimental activities grounded in real-life contexts and supported by strong classroom and laboratory experiences (Boggu & Sundarsingh, 2019). These interactions foster the exchange and generation of new ideas and knowledge.

The positive outcomes also owe to CGIS's integration of students' everyday experiences, enabling them to interpret physics concepts through their prior knowledge (Carpenter et al., 2015; Okeke, Ramaila & Ukoh, 2023). Presenting topics via story problems and employing advanced organizers facilitated meaningful engagement, consistent with Fyfe et al. (2014), who noted that narrative tasks make math and science more relevant and accessible to students. Nonetheless, the potential influence of extraneous variables cannot be ignored. Although the CGIS group's higher post-test scores suggest its superiority, a slight difference in pretest scores raises the possibility that students in the intervention group may have had an inherent advantage in ability.

Furthermore, the study found no significant interaction between intervention and students' mathematical ability on academic achievement. This implies that regardless of mathematical skill level, students benefited equally from the intervention. This contradicts findings by Chassy and Jones (2019) and Paskali and Tarmo (2025), who emphasized the importance of mathematical ability for physics achievement. Instead, these results highlight the value of contextually relevant, constructivist-aligned instructional strategies. According to constructivist learning theory, learning is a dynamic process whereby learners internalize and reconstruct knowledge based on their existing understanding and environmental evidence.

6. Conclusion

This study highlights the effectiveness of an innovative teaching method in improving students' learning outcomes in Physics. Using a quasi-experimental design and rigorous analysis, the findings provide valuable insights into Physics education. The results clearly demonstrate the effectiveness of CGIS on the academic achievement of students. Students taught with CGIS achieved higher mean post-test scores compared to those taught using conventional instructional methods, underscoring CGIS's ability to foster deeper understanding, engagement, and retention of Physics concepts.

Moving forward, this underscores the importance of continuing to explore and refine instructional strategies that enhance student engagement, critical thinking, and problem-solving skills. Through further research, targeted professional development for educators, and supportive policy reforms, we can work toward providing all students with access to high-quality Physics education that prepares them for success in the 21st century. While much emphasis has been placed on the impact of mathematical ability on learning outcomes, this study highlights the value of incorporating student feedback mechanisms to gather insights into their experiences with CGIS. Understanding students' perceptions, preferences, and challenges regarding the instructional approach can guide adjustments that better address their learning needs and further improve outcomes.

7. Recommendations

This research makes the following recommendations:
i. The adoption of contextually responsive instructional strategies in the teaching and learning of science subjects, especially Physics, is essential.

ii. Further investigations on contextually relevant Physics instruction as a means to improve students' achievement should be prioritized as a strategic imperative.

iii. Additional studies are needed to explore other variables that may influence students' attitudes towards Physics.

iv. Qualitative investigations into contextual factors and contextually responsive strategies that significantly impact students' achievement in Physics are recommended.

8. Limitations of the Study

This investigation has several potential limitations. The effect estimates in the model are based on aggregated intervention data, which may be subject to biases influencing the accuracy of the results. The estimates might be conservative due to the use of aggregate scores on students' academic achievement. The limitations can be summarized as follows:
i. A scarcity of previous studies examining the effect of CGIS on students' academic achievement in Physics.

ii. The absence of qualitative evidence, such as focus groups or interviews, to capture students' experiences with the instructional strategies and their impact on academic achievement.

iii. Insufficient delineation of other variables that might affect the study's outcomes.

iv. The duration of the study, which may have been either too short or too long, potentially influencing the results either positively or negatively.

9. Ethical Considerations

Informed consent was obtained from all participants prior to the commencement of the study, with assurances of anonymity provided. Following the study, a follow-up was conducted to expose students in the control group to the enriched instructional approach of CGIS, ensuring equitable learning opportunities for all participants.

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