ENHANCING STUDENTS' ACHIEVEMENT IN PARTICULATE NATURE OF MATTER IN PHYSICS USING STEM INSTRUCTIONAL STRATEGIES

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Abstract

The effectiveness of two STEM teaching methodologies on students' achievement in particulate matter in physics was examined in this study. Concerning the control group, the study used a non-equivalent pretest-posttest quasi-experimental approach. 211 senior secondary I (SSI) students from two schools that were purposefully sampled from 13 secondary schools in the study area served as the subjects. There were two complete courses in each of the two schools. Simple balloting was used to assign students in intact classes from each of the two schools sampled to inquiry-based and problem-based learning methodologies. These students were instructed by the same teacher in their respective schools. The Particulate Nature of Matter Achievement Test served as the study's instrument (PNMAT). Using Kuder-Richardson's formula-20 (K-R20), the internal consistency of the PNMAT was found to be 0.76. Prior to receiving therapy, the individuals in both groups underwent a pretest utilizing PNMCCT to determine their initial level of conceptions. Following therapy, the same test was given as a posttest. The instruments' acquired data were examined using the mean, standard deviation, and covariance analysis. The outcome demonstrated how instructional interventions greatly enhanced students' conceptual growth. The researchers suggested that an inquiry-based learning approach be fully embraced and put into practice as a physics educational strategy in light of the findings.

Keywords: STEM learning, Inquiry-based learning, problem-based learning, particulate nature of matter, Achievement

Introduction

Research Background and Problem

The fields of science, technology, engineering, and mathematics are referred to as STEM fields. Despite being widely used, educators are still unable to agree on a definition for the term. Any activity, policy, program, or event that incorporates many STEM disciplines is referred to as STEM (Reeve, 2013). STEM (science, technology, engineering, and mathematics) is an interdisciplinary approach to education that combines practical lessons with demanding academic concepts (Bruce-Davis et al., 2014). STEM is an interdisciplinary approach that, according to Bybee (2010), typically refers more to science or mathematics than to technology or engineering. This suggests that STEM is a method that integrates many scientific, technology, engineering, and mathematics-related subjects.

In Nigeria, STEM refers to the official and informal teaching and learning of science, technology, engineering, and mathematics at all educational levels, from primary to post-doctoral (FME, 2018). Because STEM has an impact on all facets of our lives—both as individuals and as a country—it is crucial to provide the next generation of people with the knowledge and abilities needed for the twenty-first century. Our STEM education is currently facing challenges. Poor teaching and learning environments, which are typified by inadequate laboratory equipment for experiential learning, poor and inadequate instructional materials to drive students' interest in the subjects and disciplines, and a high graduate unemployment rate due to a lack of relevant STEM skills and competencies, are just a few of the many challenges facing STEM education in Nigeria (FME, 2018). Strong political will on the part of the government at all levels is needed to address these issues and make significant investments in infrastructure and research.

In summary, governments, organizations, and scholars must work together to improve STEM education in Africa, and Nigerian schools in particular. These days, researchers are interested in this topic and working to identify efficient teaching and learning methodologies. Researchers' efforts are centered on the necessity of combining theoretical and actual learning to assist build the essential 21st century abilities. The end goal of our work is to allow people the ability to change the course of economic development and introduce the kind of innovation that the country needs to advance and prosper. Teaching with an interdisciplinary approach is encouraged by STEM education and educators. Physics is one of the subjects in the STEM fields.

In Nigerian senior secondary schools, physics is one of the science subjects that students can choose from. Physics is the study of matter's constituent parts, their characteristics, and the exchange of energy. It is important for industrialization and technological advancement (Kipngeno, 2018). According to Eryilmax (2016), physics is the most fundamental science and the basis for all other scientific disciplines. As a result, the study of matter and energy as well as the relationships governing their interaction under scientific observational, experimentally controlled, and measurement conditions constitutes the field of physics. The discovery of integrated circuits, lasers, spaceships, ships, computers, transistors, and telecommunications can all be attributed to the study of physics. Among the advantages of physics is the development of information and communication technology (ICT), which has led to the creation of a global village. Even with all of physics' advantages, students' performance and enthusiasm in the subject are below average.

The Chief Examiner's Report from May/June of the West African Examination Council (WAEC) contains cases of this failing. According to Adolphous (2018), less than 50% of students who took physics exams between 2001 and 2013 (except from 2006, 2010, 2011, and 2012) were able to receive a credit level pass or higher, allowing them to enroll in physics-intensive courses at universities. According to Onah and Achufusi (2022), this failure trend was also noted in 2015, 2017, and 2020, with better achievement in 2016, 2018, and 2019 (71%, 87%, and 80%, respectively). Therefore, the Chief Examiner for the WEAC stated that the low level of student accomplishment could be attributed to teachers' inadequate teaching methods, which may cause students to lose interest in the subject. The research suggested that instructional materials in the classroom be suitable for students' experiment demonstration and investigation. Additionally, the research suggested that educators help children develop their academic, social, and personal interests in physics. According to Kortam et al. (2018), achievement is largely influenced by interest. In order to spark students' interest during a class, a student-friendly learning environment and effective instructional tactics should be used (Taştan et al., 2018). As a result, STEM instructional strategies encourage students to actively participate in the research and exploration that results in conceptual transformation (Ugwuanyi, Ezema, & Orji 2023) as well as environments that test students' interest and curiosity and enhance their problem-solving skills (Samuels & Seymour, 2015).

A few STEM teaching techniques that help raise student engagement and achievement include inquiry-based, project-based, and problem-based learning. Thus, the purpose of this study was to determine how well two STEM teaching strategies—inquiry-based learning (IBL) and problem-based learning (PBL)—affected the academic performance in particulate matter among secondary school physics students.

Research Focus

Students need interest in order to be motivated to work toward their life goals. According to Abande (2010), interest is a feeling of worry or curiosity in something, or the focus placed on it. Magnus (2008) went on to say that enthusiasm includes all of the good emotions that students experience when attempting to learn a subject. According to Serdyukov (2017), interest is a learner's motivation that leads to the choice to enjoy a thing or activity that will ultimately provide them with ultimate fulfillment. According to Onah and Anamezie (2022), interest is an awareness-based propensity to learn about culture and science and to comprehend the world. The researchers also stated that pupils who are interested in a subject pay closer attention to it, observe it more, and engage in active thinking. Operationally, interest is defined as the positive emotions and increased focus that students experience and maintain during the learning process. Students' established interests play a major role in determining the extent and orientation of their interest in a given object or activity. Students who are interested in a subject are more likely to stay focused on it. This demonstrates the need to start efforts in the classroom to increase students' interest in science and science-related occupations. It is energy that propels the learning process and helps students attain excellent academic results. Therefore, when kids are interested in physics, they will perform better in the subject. For pupils to achieve at a higher level, it is imperative that teachers pique their interest. Therefore, teachers should use a student-centered approach to both subject matter content and materials in order to increase students' achievement and interest in physics. The constructivism hypothesis, which underpins this student-centered method, holds that students build knowledge from pre-given information by using inquiry-based and problem-based learning strategies.

Based on constructivist theory, inquiry-based learning is a student-centered approach where students create their own knowledge. Pedaste et al. (2015) define inquiry-based learning as the process of identifying novel causal links as the learner develops hypotheses and then evaluates them through observations and experiments. This suggests that children can create knowledge in accordance with Piaget's theories when inquiry-based learning is used. A type of engaged learning known as inquiry-based learning involves giving students circumstances to work through so they can come up with the information and knowledge on their own (de Jong, 2019). One recommended effective learning technique is inquiry-based learning as a paradigm. Inquiry-based learning stimulates students' interest in a subject or issue by posing questions with potential answers. This suggests that learning is fueled by students' enthusiasm in a subject, which can result in outstanding accomplishment. Because students gain information by actively participating in the learning process, this inquiry-based learning approach technique greatly increases student involvement in the learning process.

In the early stages of inquiry-based learning, students gain a greater understanding of the learning process by creating questions with potential answers. This has the educational benefit of increasing pupils' knowledge of the subject or topic of study while retaining their interest and attention. Through questioning every aspect of the learning process and allowing students to formulate their own questions for investigation, inquiry-based learning encourages critical thinking and brainstorming of solutions among students. According to Aktamiş et al. (2016), students' academic achievement was positively and significantly impacted by inquiry-based learning. Additionally, the study discovered that their attitudes toward science and their ability to absorb science were positively and somewhat impacted by this particular teaching and learning strategy. Once more, the study discovered that, in comparison to the traditional teaching approach, the inquiry-based learning approach utilized in science education had far more substantial influence on student accomplishment rather than on their attitudes toward science and their abilities in the scientific method.

Problem-based learning is an additional approach to STEM education in addition to inquiry-based learning. Although there is general agreement that problem-based instruction should be used as a STEM instructional strategy, there is a dearth of literature on how its instructional strategies affect students' achievement and interest in physics due to the ambiguity of the approach and the lack of a consensus definition among researchers. With problem-based instruction, which is a student-centered approach, the teacher facilitates learning by presenting pupils with a vague, real-world problem. When it comes to assessment, this educational approach to learning emphasizes the process above the final product (Angelle, 2018). Research revealed that problem-based learning might be either student- or teacher-directed. While Nordin, Samsudin, and Harun (2017) proposed that it should be student-directed, Drake and Long (2009) asserted that it should be teacher-directed. To varied degrees, group work or collaboration is a crucial component of problem-based learning (Robinson, Dailey, Hughes, & Cotabish, 2014). However, there is a widespread agreement that the final solution should not be the primary emphasis of PBL evaluation; rather, the learner's approach and thoroughness in answering the problem should be highlighted (Sengur & Tekkaya, 2006). Regarding the kind of challenges that should be used in problem-based learning, researchers are divided. While some suggest that the challenges should be poorly defined and/or meticulously planned and manufactured, Gomez-Pablos, Martín del Pozo, and Munoz-Repiso (2017) emphasize on problems that involve real-world events (Wright, Shumway, Terry, & Bartholomew, 2012). The student's engagement with resources that lead to authentic and experiential learning is an intriguing aspect of inquiry-based and problem-based learning.

Research Aims and Research Questions

This study examined the effect of STEM instructional strategies on secondary school students' achievement in particulate nature of matter concepts in physics in FCT Abuja. Specifically, this study investigated the effects of inquiry-based learning and problem-based learning strategies on students' achievement and interest in particulate nature of matter. The following questions were answered (i) What are the mean achievement scores of students taught particulate nature of matter using STEM inquiry-based learning strategy and those taught using the STEM problem-based learning strategy? (ii) What are the mean interest scores of students taught particulate nature of matter using STEM inquiry-based learning strategy and those taught using the STEM problem-based learning strategy? While two hypotheses were raised to guide the study (i) There is no significant difference in the mean achievement scores of students taught particulate nature of matter using STEM inquiry-based learning strategy and those taught using the STEM problem-based learning strategy (ii) There is no significant difference in the mean interest scores of students taught particulate nature of matter using STEM inquiry-based learning strategy and those taught using the STEM problem-based learning strategy

Method

Research Design

With regard to the control group, the study used a non-equivalent pretest-posttest quasi-experimental approach. Nworgu (2015) asserts that the design prevents individuals from being assigned to experimental groups at random. Nworgu went on to say that pre-existing or entire classes are utilized. In this investigation, entire classes were assigned to experimental settings. Ezema et al. (2022), Eze et al. (2021), and Ugwuanyi et al. (2020) have all used this design.

Ethical Statement

The university committee on research ethics gave the researchers ethical permission to carry out this investigation. In addition, informed consent forms were given to the subjects to complete and sign prior to the experiment starting.

Study Participants

211 senior secondary school year 1 (SSI) students with an average age of 14 years who had passed physics in the previous term served as the study's sample. After completing Nigeria's nine-year mandatory basic education program, these kids are currently enrolled in their first year of senior secondary education. 5,621 senior secondary school year one physics students from 13 public senior secondary schools in the Bwari Area Council of the Federal Capital were used to create this sample for the 2021–2022 academic year. The sample was intentionally selected from two senior secondary schools located in the FCT's Bwari Area Council. Using simple random sample by balloting, two whole classes from each of these schools were selected to participate in either inquiry-based learning or problem-based learning. This suggested that 106 students from two intact classes of 53 and 53 participated in the inquiry-based learning treatment, whereas 105 students from two intact classes of 53 and 52 participated in the problem-based learning therapy.

Instrument's Validation and Reliability

Data was gathered using the Particulate Nature of Matter Achievement Teat (PNMAT). A ten-item multiple-choice test called the particle Nature of Matter Achievement Test (PNMAT) was created using the ideas of particle matter. The researchers created the PNMAT items in order to evaluate students' mastery of the subject's principles. There are four multiple-choice alternatives for each PNMAT item, and only one of them is the right response. The PNMAT was constructed using a table of specifications that the researchers on the topics had provided. The instrument is graded by deducting zero points for any incorrect response and awarding one mark for the right answer. The tool was put through a comprehensive validation process by physics educators and test development experts before being put through a trial run. The Kuder-Richardson's formula–20 (K-R20) was used to determine the PNMAT's internal consistency, which came out to be 0.76.

The researchers created lesson plans using PBL and IBL techniques. On each of the models, lesson plans lasting five periods were created. Five experts—two from the Measurement and Evaluation unit, two from the Physics Education unit of the Department of Science Education, and one from the Educational Psychology unit of the Department of Educational Foundation—were used to face validate the instruments and the lesson plans. In particular, the experts were asked to verify whether or not each instrument item measures what it is supposed to measure, as well as whether or not the language used to write the items in the instruments is ambiguous, whether or not the items are appropriate for the students' class, and whether or not the instructions are clear for the research subjects. The experts likewise provided face validation for copies of the instructional plans. The final version of the instrument and the lesson plans were developed using the validators' recommendations and remarks.

Experimental procedures

Before the trial started, the researchers gave the research assistants training on how to use the prepared lesson plans to implement inquiry-based learning and problem-based learning. During the training, research assistants used a class of SS1 children from a nearby school to practically demonstrate the stages required in the two instructional styles. The administration and collection of the instruments used for data collection were also covered in the training.

Two days were dedicated to the training. The first day's activities entailed teaching the research assistants the two STEM methodologies for instructing the two groups, with a focus on how to choose materials that will spark and maintain interest and create spaces that support inquiry and knowledge building. Prior to the research assistants being permitted to conduct the procedures independently, the researchers performed a demonstration of these stages. On the second day, SS1 kids from the neighbourhood participated in a hands-on presentation of the tactics. Following their observations, the researchers gave the research assistants comments to help them become more adept at using these techniques and following their lesson plans. By the time the training was over, the researchers were confident that the research assistants had a thorough understanding of every step of the research process, had addressed any concerns, and were prepared to help and follow the researchers' carefully laid out lesson plan.

The students in the experimental groups are divided into two groups: the first group uses an inquiry-based learning technique to teach physics topics, and the second group uses a problem-based learning strategy. Prior to the commencement of treatment, the students were administered the PNMAT and PIS as a pretest to gauge their level of prior achievement and interest in the material. For six weeks, the students received the treatment in their respective groups. The identical PNMAT and PIS were then provided to each group of students to complete as a posttest. The tests were given simultaneously, and the scripts were gathered right away for scoring purposes. Data analysis was the last step before the pretest and posttest results were examined.

Data analysis procedure

While analysis of covariance was employed to test the hypotheses at the.05 level of significance, mean and standard deviation were utilized to examine the data in order to address the research objectives.

Results

The results are presented in line with the research question posed and the hypothesis that guided the study.

Research Question 1: What are the mean achievement scores of students taught particulate nature of matter using STEM inquiry-based learning strategy and those taught using the STEM problem-based learning strategy?

Table 1: Mean analysis of physics achievement scores of students taught particulate nature of matter using inquiry based learning and problem based learning

		Pretest		**Posttest**		
Group	**N**	**Mean**	**SD**	**Mean**	**SD**	**Mean gain**
Inquiry Based Learning	106	8.14	1.67	18.98	2.56	10.84
Problem Based Learning	105	8.23	1.34	16.98	2.78	8.75

Inquiry-based learners had a mean achievement score of (M = 8.14, SD = 1.67) prior to instruction, according to Table 1, whereas problem-based learners had a mean achievement score of (M = 8.23, SD = 1.34). This implies that the two groups' initial levels of success were about equal. The problem-based learning group had a mean achievement score of (*M* = 18.98, *SD* = 2.56) with a mean gain of (*M* = 10.84), whereas the inquiry-based learning group had a mean achievement score of (*M* = 16.98, *SD* = 2.78) with mean increase of (*M* = 8.75) following the instruction. The group that was taught inquiry-based learning had a larger mean gain than the group that was taught problem-based learning, as evidenced by the difference in their mean gain achievement scores.

Hypothesis 1: There is no significant difference in the mean achievement scores of students taught particulate nature of matter using STEM inquiry-based learning strategy and those taught using the STEM problem-based learning strategy.

Table 2: Analysis of covariance of the effect of inquiry-based learning and problem-based learning on students' achievement

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	8.379[a]	2	4.189	3.323	.015	.087
Intercept	3078.140	1	3078.140	2441.503	.000	.761
PrePNMAT	2.559	1	2.559	2.030	.213	.032
Instructional Strategy	12.874	1	12.874	11.117	.000	.134
Error	240.789	208	1.158			
Total	17200.000	211				
Corrected Total	270.616	210				

a. R Squared = .031 (Adjusted R Squared = .022)

Table 2 demonstrates that instructional strategies had a substantial impact on students' achievement in particulate matter, $F\ (1, 208) = 11.117$, p =.000). The researchers rejected the null hypothesis since the probability value of.029 is less than the probability level of.05. This indicates that the group taught using inquiry-based learning technique outperformed the group taught using problem-based learning strategies in terms of mean achievement scores. Students who were taught particulate matter utilizing inquiry-based learning had higher accomplishment scores. Furthermore, the impact size of .134 indicates that the students' exposure to an inquiry-based learning technique was responsible for 13.4 percent of the variation in their success scores. This demonstrates that students achieve more when using the inquiry-based learning strategy than when using the problem-based learning strategy.

Discussion of the Findings

According to the study's findings, inquiry-based learning significantly outperformed problem-based learning in terms of students' performance in physics' particulate matter and particle nature. Accordingly, there was a significant difference in the mean achievement scores of students who were taught particulate matter through inquiry-based learning versus those who were taught problem-based learning, with the students who were taught inquiry-based learning outperforming the students who were taught problem-based learning strategy. Based on the difference in the students' mean accomplishment scores, it may be concluded that inquiry-based learning improves student achievement more than problem-based learning. Because inquiry-based learning is entirely student-driven, as opposed to problem-based learning, which may be teacher-directed, it outperforms problem-based learning in terms of improving students' achievement in particulate matter. Teacher-directed problems could be confusing or challenging for students due to the cognitive and affective characteristics of the teachers. In the early stages of inquiry-based learning, students may develop a greater awareness of the learning process by creating questions with potential answers. This has the educational impact of making the pupils more knowledgeable about the subject or topic of study and the interpretation of the concepts. The results are consistent with Aktamiş et al. (2016), who found that inquiry-based learning improved students' academic performance at higher levels and had a favorable, medium-level impact on their attitudes toward science and science process abilities. The findings support the report's assertion that inquiry-based learning encourages students to actively participate in the learning process by presenting their own queries about the topic being discussed in order to increase accomplishment (Chiang, Yang & Hwang, 2014). According to earlier research (Ugwuanyi, Ezema & Orji, 2023; Umahaba, 2018; Labobar et al., 2017; Okafor, 2016; Tuna & Kacar, 2013), constructivist learning approaches like 5E instruction and related inquiry models improved students' achievement. These findings are consistent with those findings.

This result is in line with that of Wright et al. (2012), who found that students' achievement was higher when direct instruction was used instead of problem-based learning when teaching geometry program Geometer's Sketchpad to students. Robinson, et al. (2014), who found that PBL students (n = 67) applied their scientific method knowledge more effectively when faced with real-world situations than the control group (n = 60), supports the findings of the current study. This demonstrates how problems in the real world can spark interest in a subject. The use of problem-based learning techniques improves student accomplishment in terms of subject comprehension. The pupils' enjoyment in understanding the ideas of particle matter kept them engaged in the subject.

Conclusion and Recommendations

The study looked into how well students performed in physics classes covering particulate matter and the effectiveness of inquiry-based and problem-based learning approaches. Both post-achievement and post-interest scores for students who were exposed to STEM inquiry-based learning and problem-based learning techniques were higher than those of their pretest. The effectiveness of STEM initiatives in raising students' interest and achievement has been demonstrated. In particular, students' achievement in particulate matter in physics is improved more by the inquiry-based learning strategy than by the problem-based learning strategy. This might be the case because, in contrast to students in problem-based learning groups, students in inquiry-based learning groups engage and interact with one another and the environment in a more investigative and exploratory manner. It is possible that students' interest in the concepts and subject matter increases as they solve more problems given to them during education. They feel good about the experience, and it gives them drive to keep studying the material. This could focus the students' attention on the material, goal-setting, and instructional activities to help them complete more assignments and goals. In order to attain this goal, incorporating STEM teaching methodologies into physics classrooms will raise student achievement and spark curiosity about the ideas. The researchers therefore recommend that:

1. As a physics instructional technique, inquiry-based learning should be thoroughly embraced and put into practice.

2. It is recommended that physics teachers receive in-service training on the application of STEM learning methodologies, such as inquiry-based and problem-based learning paradigms.

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