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Engaging 4MAT Instructional Strategy on learners' Conceptual Understanding, Cognitive Styles, and Learning Outcomes in Secondary School Concepts of Radioactivity

Emmanuel Ikechuku Abamba

ieabamba@delsu.edu.ng

Delta State University

Omomaro Thompson Imoniwe

Delta State University

Akpomudiare Helpus Efe

Delta State University

Janice Imuzuokena IRORITERAYE-ADJEKPOVU

Delta State University

Urhievwejire Ochuko AGBORO-ERAVWOKE

Delta State University

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Abstract

This study examined the effects of the 4MAT Instructional Strategy on Students' Conceptual Understanding, Cognitive Styles, and Learning Outcomes in Secondary School Physics. The study used a non-randomised pretest-posttest control-group quasi-experimental design. The study population consisted of twenty-nine thousand, seven hundred and eighty-four (29,784) SSII students in Delta North. Three hundred and five (226) students, as well as four physics teachers, were sampled from four public secondary schools in the Senatorial District. Six research questions were raised and answered, and six hypotheses were tested at the 0.05 level of significance. The instruments for the study included a Two-Tier Diagnostic Conceptual Test and Cognitive Style Inventory. The validity and reliability of the Two-Tier Diagnostic Conceptual Test, face and content validity. While the Kuder-Richardson formula 20 was used to establish reliability, a reliability coefficient of 0.82 was obtained. The statistical tools used were the mean, standard deviation, and Analysis of Covariance (ANCOVA) to test the formulated hypotheses. The results, amongst others, showed significant differences in conceptual understanding and learning outcomes between students taught with the 4MAT instructional strategy and those taught with the lecture method, with $F(1,302) = 1893.100$, $p = 0.000$, and $F(1,302) = 1688.472$, $p = 0.000$, respectively. Based on the findings, it was recommended, among others, that the 4MAT instructional strategy be employed in faculties of education as a teaching method for teacher-trainees to gain competence in its use.

Introduction

Physics is a natural science that studies matter, energy, and their interactions. Physics is the study of natural phenomena at their most fundamental levels and in their most fundamental manner (Anyakoha, 2016). Physics is one part of science, a collection of knowledge, ways of thinking, and investigation (Salam et al., 2024). Physics is the most fundamental and the root of every field of science and technological advancement (Eryilmaz, 2016). Physics and technology form an inseparable unity, constituting a complementary culture of science and technology, with one side embodying the essence of science and the other the meaning of technology. The development of learning technology is used to deepen students' understanding of physics, so that they are comfortable and happy while learning. Physics, as part of science and technology, also experienced the development of theory and its application (Salam et al, 2024). This is because physics, as one of the core subjects offered in Nigerian schools, serves as the foundation for the nation's technological advancement and human resource development (Onah & Achufusi, 2022).

Despite the importance of Physics, many factors affect students' learning outcomes, including teaching strategies, learning environment, motivation, epistemological beliefs, and attitudes towards Physics (Arra, 2021). In Physics teaching, the appropriate use of effective research-based teaching strategies can help students learn fundamental concepts and improve their conceptual understanding and learning outcomes (Appiah-Twumasi, 2021). The fundamental principle of Physics teaching is about helping students understand scientific principles and develop scientific thinking skills (Appiah-Twumasi, 2021).

Studying physics is a process of acquiring knowledge and understanding of the basic principles and laws that govern the behaviour of matter and energy in the universe (Salam et al, 2024). According to them, this means that to achieve these goals, one must have a sufficient understanding of Physics concepts and then apply them in similar and novel areas. Effective Physics learning involves developing a strong foundation in concepts, critical thinking, and problem-solving. It also requires a deep understanding of scientific methodology, including hypothesis testing, experimentation, and data analysis. For all of these to be effectively achieved, an efficient teaching method must be employed; one such method is the 4MAT instructional strategy.

The four-mode application technique, commonly called the 4MAT, was developed by Bernice McCarthy to engage all learners and address their learning styles. It's a model built on experiential learning theory (Iikorucu et al., 2022), with learners expected to gain experience through increased interaction with the subject matter. According to Maher et al. (2021), the model is based on a range of teaching strategies that are consistent with learners' characteristics. The philosophy is on the blend between the basic principles of human development theories and the human brain functions. The 4MAT strategy has been considered effective in teaching all learners, regardless of level of study or discipline (Omar Salar Samer & Mdimmiad, 2020). Chukuwkuka & Ajaja (2022) opined that the model is based on the premise that individuals perceive and process information differently. They stated that learners' perception of new information aligns with their experience and conceptualisation, and that learners' experience may be through sensations, emotions, feelings, and so on. The model, being an integrated approach to teaching, employs different strategies cum methods anchored on the constructivist method (Burcu & Filiz, 2018). According to them, 4MAT helps students develop personal understanding and perception, as well as perform cooperative activities.

The four stages of 4MAT are:

1. Experiencing: this stage helps to engage learners with activities and experiences that are concrete, which will make them curious and active. This can be done by relating activities and experiences to real-world scenarios. This is the stage of connecting and attending to experiences. Such activities ask questions about experiences that are unveiled. This stage is more about teacher-student interaction.
2. Conceptualisation: In this stage, students begin to find the underlying concept and the theories behind such experience; this stage is more teacher-centred. This stage could involve lectures, discussions, and extensive readings to help students discover why certain experiences exist. This is the stage? A stage of practising concepts and skills. In this stage, the teacher teaches.

3. Applying: this stage involves the application of learned concepts into practice. This stage involves the student carrying out confirmatory experiments and hands-on activities. This is the how stage. These steps, which involve acquiring skills and concepts, are extended and practised. This is done by students being able to set up successful practice. This is the stage of the teacher's coaching/facilitating.
4. Perform (IF?) Retiring: this stage, students reflect on the learning, analyse their successes and challenges and make connections to future learning through discussion. This is the stage of adaptations. In this stage, learners refine what they have learned and apply it to their lives. This is also known as the stage of self-discovery. This stage affords the learners the opportunity to interact with the teacher, enabling the teacher to evaluate and remediate. While the first two are on grasping experience, the latter two are on transforming experience.

Empirical studies on the 4MAT instructional strategy have been quite revealing. For instance, Quar et al. (2020) found a significant difference between learners taught social studies using the 4MAT mode and those taught using the traditional method. Mather (2021) found a significant difference between the experimental and control groups in post-administration scores on the creative thinking test as a whole and on each of its skills, favouring the experimental group. Kanwalpreet & Anjum (2023) found that the 4MAT strategy group was significantly associated with retention when employed in teaching economics compared with the conventional teaching strategy. Also, the study showed a significant difference between reproducing and constructive learning styles in students' retention in economics. Chukwuka & Ajaja (2022) found that biology students taught using the 4MAT method achieved significantly better outcomes than those taught using the lecture method. The study also found that 4MAT is not sex-biased. Studies by Dabit et al (2024) showed that the 4MAT instructional strategy improved students' interest in geometry. The study confirmed that 4MAT instruction is not sex-biased in improving interest. likorucu et al. (2022) found that the integrated 4MAT strategy produced a significant difference in favour of the experimental group on student scores in critical thinking and disposition when employed. Burcu & Filiz (2018) found that the attainment level and mean scores favoured the experimental group taught through an integrated 4MAT approach. Inel (2018) found an improved achievement when the 4MAT model was employed in teaching students. Despite technological advancements in education, many students continue to struggle with understanding basic concepts. This can be partly attributed to the absence of pedagogical strategies that effectively promote conceptual engagement and foster active cognitive engagement. Conventional instructional methods have demonstrated limited effectiveness in achieving lasting conceptual understanding (Echantoufi et al., 2025). One of such methods is the 4MAT instructional strategy.

Conceptual understanding is a person's ability to see connectedness between concepts and procedures, as well as being able to apply a given principle in a variety of contexts and explain why some facts are consequences of others (Hussein & Csiskos, 2023). Conceptual understanding refers to a deep and thorough comprehension of fundamental concepts and principles within a particular subject or field of study. It implies the capacity to connect, apply, and manipulate these concepts to solve problems after thinking critically (Babalola, 2025). A robust conceptual understanding empowers individual students to

apply their knowledge flexibly, surmount complex challenges, and establish meaningful correlations with related ideas or disciplines (Mills, 2016, in Babalola, 2025). According to Babalola, conceptual understanding constitutes a cornerstone of critical thinking and higher-order cognitive capabilities, affording individuals the capacity to extrapolate their understanding to novel contexts and adapt to unfamiliar scenarios. Conceptual understanding refers to what learners know and understand about a concept, that is, generalisations learners can develop about the nature or properties of that concept (Anim-Eduful, 2022). Conceptual understanding requires students to organise facts and ideas into a significant scientific concept. In conceptual teaching, teachers explain why particular operations work in specific ways. Students with conceptual knowledge can transfer their knowledge to new mathematical situations (Hussein & Csiskos, 2023). According to Nwankwo (2021), integration and functional grasp of science, especially physics, are very useful components of conceptual understanding. Students with conceptual understanding know why an idea is important and the kind of contexts in which it is useful. They have organised their knowledge into a coherent whole, enabling them to transfer what they learn in one situation to another area of study. Rote learning has no place in conceptual understanding. Conceptual understanding involves seeing the connection between concepts and procedures.

Empirical Studies on conceptual understanding have been revealing, even though few. First, Anim-Eduful & Adu-Gyamfi (2022) found that students demonstrated conceptual difficulties, in the form of alternative conceptions, and factual difficulties in organic qualitative analysis. Zulhipri et al. (2022) observed that PhET Interactive Simulations require improvements or additional features to help students better understand the conceptual understanding through analogies of the movement of product and reactant molecules in the equilibrium system. Also, Babalola (2025) found no significant influence of on-site learning on students' Conceptual understanding of the Mole Concept. However, Echantoufi et al (2025) found a significantly greater improvement in students' conceptual understanding of Newton's law of gravitation in the experimental group exposed to an Interactive Multimedia Learning Environment (IMLE), compared to the control group receiving traditional instruction. An effective method will also take into account learners' preferred learning styles. It is believed that 4MAT will account for all learning styles (cognitive styles) within one cycle of the learning process.

Cognitive styles refer to the preferred way an individual processes information (Abamba et al, 2024). It represents how individuals not only perceive information but also process and interact socially with it. A learner's cognitive style can be field-dependent (FD) or field-independent (FI). The field-dependent learner is one who sees concepts holistically, with great difficulty separating items from their background, but who relies on group work, teacher feedback, and social cues for effective learning. The field-independent learner is an analytical, self-motivated, not dependent in group work for reinforcement, but good at identifying details personally. An X-ray of the learning styles and the various teaching methods reveals similarities between them. For example, field-dependent learners, based on their characteristics, can be taught using student-centred methods, where they will be made to collaborate among themselves and with the teachers. Field-independent learners can be taught using a student-centred approach, in which they are encouraged to work independently to a considerable extent (Agboro-Eravwoke et al., 2025).

Studies have shown that the teaching method employed can bridge the learning outcomes of both FD and FI learners (Agboro-Eravwoke et al., 2025; Abamba et al., 2024).

Sex refers to the biological characteristic of being a male or a female. Sex can influence various aspects of human life, including learning outcomes. A lot of factors could contribute to this difference, which include the method of instruction employed. Results on the effects of methods on sex have been mixed. While some found no significant difference in learning outcomes (Chukwuka & Ajaja, 2022; Dabit et al., 2024; Eze et al., 2024), others found a significant difference between sex and instructional method.

Therefore, the general purpose of this study is to examine the effects of the 4MAT Instructional Strategy on Students' Conceptual Understanding, Cognitive Styles, and Learning Outcomes in Secondary School Concepts of Radioactivity.

Research questions

The following research questions were raised and answered.

1. 1. To what extent does the 4MAT instructional strategy influence students' conceptual understanding of Physics compared with the conventional lecture method?
2. 2. How do the learning outcomes of students taught Physics using the 4MAT instructional strategy differ from those of students taught using the conventional lecture method?
3. 3. To what extent does the conceptual understanding of field-dependent and field-independent learners differ following instruction through the 4MAT instructional strategy and the conventional lecture method in Physics?
4. 4. What difference exists in the learning outcome of field-dependent and field-independent learners exposed to the 4MAT instructional strategy and those taught through the conventional lecture method in Physics?
5. 5. How does the learning outcome of male and female learners differ when taught Physics using the 4MAT instructional strategy compared with the conventional lecture method?
6. 6. How does the conceptual understanding of male and female learners compare when they are taught Physics using the 4MAT instructional strategy versus the conventional lecture method?

Research hypotheses

The following were raised and tested

Ho_1. There is no significant difference in the conceptual understanding of students taught Physics using the 4MAT instructional strategy and those taught using the conventional lecture method.

Ho_2. There is no significant difference in the learning outcomes of students taught Physics using the 4MAT instructional strategy and those taught using the conventional lecture method.

Ho_3.There is no significant difference in the conceptual understanding of field-dependent and field-independent learners taught Physics using the 4MAT instructional strategy and those taught using the conventional lecture method.

Ho_4. There is no significant difference in the learning outcome of field-dependent and field-independent learners taught Physics using the 4MAT instructional strategy and those taught using the conventional lecture method.

Ho_5. There is no significant difference in the learning outcome of male and female learners taught Physics using the 4MAT instructional strategy and those taught using the conventional lecture method.

Ho_6. There is no significant difference in the conceptual understanding of male and female learners taught Physics using the 4MAT instructional strategy and those taught using the conventional lecture method.

Methods and Material

The study adopted a quasi-experimental pre-test, post-test, non-equivalent control group design. This design was considered appropriate because the study was conducted using intact classes in their natural school settings, making random assignment of individual students to experimental and control groups impracticable. Consequently, participants were assigned to groups based on their existing class membership, a characteristic feature of quasi-experimental research. The design enabled the researcher to compare the effects of the 4MAT instructional strategy and the conventional lecture method on students' learning while controlling for initial group differences through the administration of a pre-test. The independent variable in the study was the instructional strategy, operationalised as the 4MAT instructional strategy and the conventional lecture method. The dependent variables comprised students' conceptual understanding and learning outcomes in Physics, while cognitive style (field-dependent and field-independent) served as an attribute variable. Sex (male and female) was treated as a moderator variable to determine whether the effectiveness of the instructional strategies varied across sex.

The instruments used for data collection were:

1. Two-Tier Diagnostic Conceptual Test
2. Cognitive Style Inventory

The Two-tier Diagnostic Conceptual Test (TDCT) comprises 40 multiple-choice items. Tier 1 consists of the multiple-choice conceptual question, while Tier 2 consists of the reason/explanation for the selected item. Questions were drawn from various aspects of radioactivity; questions 1–7 generated questions on the concept of atomic structure and nuclear stability; questions 8–13 elicited questions on nuclear stability; questions 14–22 covered the types of radioactivity; questions 23–30 covered decay laws and half-life; and lastly, questions 31–40 were on detection, applications and hazards. The Cognitive Style

Inventory consists of thirty-three (33) items that elicited questions from the participants and helped in determining whether a student is a field-dependent or a field-independent learner. It is a four-point scale of Strongly Agreed (SA), Agreed (A), Disagreed (D), and Strongly Disagreed (SD).

The Two-Tier Diagnostic Conceptual Test was validated through face validity and content validity. To assess face validity, three experts were engaged. The first is a teacher with at least 10 years' experience in a government secondary school. This ensured that the teacher is not just a physics graduate but is registered with the Teacher Registration Council of Nigeria. The second is a lecturer in science education who examined the work and instrument to ensure the instrument's organisation, and, lastly, a lecturer from measurement and evaluation who vetted the instrument and ensured it could measure conceptual understanding. To ensure content validity, a table of specifications was employed to align the instrument with the curriculum.

Table 1
Table of Specification for 40-item test on radioactivity

Content Area	**Objectives**				
	Knowledge	**Comprehension**	**Application**	**Analysis**	**Total**
Atomic Structure and Nuclear Stability (17.5%)	3	2	1	1	7
Nature of Radioactivity (15%)	2	2	1	1	6
Types Of Radiation (22.5%)	3	2	2	2	9
Decay Law & Half-Life (20%)	3	2	2	1	8
Detection, Applications & Hazards (25%)	5	3	1	1	10
Total (100%)	16	11	7	6	40

TDCT was administered to 30 subjects outside the study district to establish the study's reliability. The Kuder-Richardson formula 20 was used to calculate the reliability, yielding a reliability coefficient of 0.82; hence, TDCT was adjudged reliable. The Cognitive Style Inventory was adopted from an earlier study by Abamba et al. 2024

Participants

The population of the study consist of twenty-nine thousand, seven hundred and eighty-four students spread across one hundred and seventy-seven (177) public schools in Delta North. Two hundred and three hundred and five (305) students, as well as four physics teachers, were sampled from four public secondary schools in the Senatorial District. The sampling technique used was balloting with replacement. The secondary schools in the Delta North Senatorial District were listed. The names of the schools were written on pieces of paper and folded. Four schools were selected using the withdrawal-with-replacement method, one at a time.

Treatment Procedure

Step 1: Experiencing & Reflecting (Why?)

This phase is intended to stimulate students' interest and expose them to real-world situations, such as nuclear accidents and medical X-rays. The instructor raises important issues, such as why certain atoms are stable while others disintegrate and release energy. What causes some metals to be radioactive? At this point, students must consider why matter behaves differently at the atomic level based on their own observations and preconceived notions about atoms and radiation. It is more of a think-pair-share conversation to assess this level.

Step 2: Conceptualising (What?)

At this stage, formal notions and scientific explanations of atomic structure and nuclear stability are presented. The instructor asks the class to describe the extra-nuclear electrons and the nucleus, which consists of protons and neutrons. Additionally, the students were required to define isotopes, mass numbers, atomic numbers, and nuclides. Additionally, the instructor introduces nuclear stability in terms of the neutron-proton (N/Z) ratio and asks the students to explain radioactivity and nuclear instability. At this point, students can see charts, diagrams, and symbolic representations in addition to taking organised notes. To assess this phase, the instructor asks the pupils to describe nuclear instability. Here, the students' proficiency in utilising appropriate scientific terminology to describe atomic structure and nuclear stability.

Step 3: Applying & Practising (How?)

This phase is intended to foster procedural comprehension and problem-solving abilities related to atomic structure. Here, the instructor shows how to calculate the atomic number, mass number, and neutron number. Provides pupils with isotope cards for categorisation exercises and helps them distinguish between stable and unstable nuclei. Students now work both independently and in groups to tackle numerical issues. Determine whether the following nuclides are stable or unstable depending on the N/Z ratio. At this point, students are evaluated on their ability to accurately solve problems involving atomic structure and to classify nuclei by stability.

Step 4: Integrating & Creating (If?)

This phase extends learning to possible scenarios and real-world applications. At this point, the professors give application-based activities, such as "What would happen if Carbon-14 were perfectly stable?" Why, in spite of their hazard, are some radioactive materials useful? Students describe uses including medical diagnostics, nuclear energy, and radiocarbon dating. As part of their assessment, students are required to apply their understanding of nuclear stability to both novel and real-world scenarios.

Method of data analysis

In scoring the TDCD, 2 points were awarded if both tiers were correct, 1 point if Tier 1 was correct and Tier 2 was incorrect, and 0 points if Tier 1 was incorrect. Therefore, the maximum score is 80. To account for learning outcomes, only tier 1 scores will be used. This will generate a maximum score of 40 and will be converted to a percentage. In determining the level of conceptual understanding of participants, the mean score will be converted to a percentage, and the range will be interpreted below:

Score Range Interpretation

80–100% Sound conceptual understanding

60–79% Partial understanding

40–59% Fragmented understanding

Below 40% Misconception-dominated

For the cognitive style inventory, 4 marks for SA, 3marks for A, 2 marks for D, and 1 mark for SD. In determining students' cognitive style, those who scored 66 or higher were considered field-independent learners, while those who scored below 65 were considered field-dependent learners. To answer the research questions, the mean and standard deviation was used, Analysis of Covariance (ANCOVA) was used to test the hypotheses at the 0.05 level of significance.

Results and Discussion

Research one: To what extent does the 4MAT instructional strategy influence students' conceptual understanding of Physics compared with the conventional lecture method?

To answer research question one, the mean and standard deviation were used, and the results are presented in Table 2.

Table 2
Mean and Standard Deviation (SD) of Conceptual Understanding between students taught with the lecture method and the 4MAT Instructional Strategy.

Source of variation	Methods	N	Mean (%)	SD	Conceptual Standing
Pre-conceptual understanding	Lecture	158	14.26	3.70	Misconception Dominated
	4MAT	147	14.31	3.77	Misconception Dominated
Post-conceptual understanding	Lecture	158	47.53	6.59	Fragmented Understanding
	4MAT	147	80.43	6.63	Sound conceptual Understanding

The result of Table 2 showed that at the pretest level, the mean pre-conceptual understanding is 14.26 for the lecture method and 14.31 for the 4MAT instructional strategy. This result showed that both groups were misconception-dominated in the Radioactivity before treatment. The result also showed that the post-conceptual mean scores were 47.53 for the lecture method and 80.43 for the 4MAT instructional strategy. This implies that the lecture method increased their conceptual understanding from a misconception-dominated level to a fragmented understanding, whereas 4MAT increased it from a misconception-dominated level to a sound conceptual understanding.

Ho_1. There is no significant difference in the conceptual understanding of students taught Physics using the 4MAT instructional strategy and those taught using the conventional lecture method.

To test hypothesis one, Analysis of Covariance was employed, and the result is presented in Table 3.

Table 3
Analysis of Covariance (ANCOVA) for conceptual understanding between lecture method and 4MAT instructional strategies. Dependent Variable: Post Conceptual Understanding

Source	Type III sum of squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	82528.396[a]	2	41264.198	947.973	.000	.863
Intercept	74517.699	1	74517.699	1711.914	.000	.850
Preconceptual understanding	85.676	1	85.676	1.968	.162	0.006
Methods	82404.510	1	82404.510	1893.100	.000	.862
Error	13145.722	302	43.529			
Total	1321006.000	305				
Corrected Total	95674.118	304				
a. R Squared=.863 (Adjusted R Squared=.862)						

Table 3 showed that F(1, 302) = 1893.100, p = 0.000, which is significant. Therefore, there is a significant difference between the 4MAT instructional strategy and the lecture method in students' conceptual understanding of Physics. Based on the Adjusted R Squared value, the 4MAT instructional strategy accounted for 86.2% of students' conceptual understanding.

Research Question 2: How do the learning outcomes of students taught Physics using the 4MAT instructional strategy differ from those of students taught using the conventional lecture method?

To answer research question two, the mean and standard deviation were used, and the results are presented in Table 4.

Table 4
Mean and Standard Deviation (SD) of students' learning outcomes between students taught with the lecture method and 4MAT Instructional Strategy

Source of variation	Methods	N	Mean	SD
Pretest scores	Lecture	158	13.65	4.32
	4MAT	147	13.71	3.77
Posttest scores	Lecture	158	48.72	7.00
	4MAT	147	78.76	5.61

The result of Table 4 showed that at the pretest level, the mean pretest scores are 13.65 for the lecture method and 13.71 for the 4MAT instructional strategy. Also, the posttest mean scores were 48.72 for the

lecture method and 78.76 for the 4MAT instructional strategy. A mean difference of 30.04 was obtained. This implies that students taught using 4MAT achieved greater understanding of the concept of radioactivity. To determine if this difference is significant, ANCOVA was employed, and the result is presented in Table 5

Ho_2. There is no significant difference in the learning outcomes of students taught Physics using the 4MAT instructional strategy and those taught using the conventional lecture method.

To test hypothesis two, Analysis of Covariance was employed, and the result is presented in Table 5.

Table 5
Analysis of Covariance (ANCOVA) for learning outcome between lecture method and 4MAT instructional strategies. Dependent Variable: Post-learning outcome

Source	Type III sum of squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	68711.705[a]	2	34355.852	844.791	.000	.848
Intercept	97322.012	1	97322.012	2393.094	.000	.888
Pretest	20.272	1	20.272	.498	.481	0.002
Methods	68666.518	1	68666.518	1688.472	.000	.848
Error	12281.692	302	40.668			
Total	1299363.000	305				
Corrected Total	80993.397	304				
b. R Squared=.848 (Adjusted R Squared=.847)						

Table 5 showed that F(1, 302) = 1688.472, p = 0.000, which is significant. Therefore, there is a significant difference between the 4MAT instructional strategy and the lecture method on students' learning outcomes in Physics. Based on the Adjusted R Squared value, the effect of the 4MAT instructional strategy on students' learning outcomes is 84.7%.

Research Question 3: What is the difference between the conceptual understanding of field-dependent and field-independent learners taught using the 4MAT instructional strategy and the lecture method in Physics?

To answer research question three, the mean and standard deviation were used, and the results are presented in Table 6.

Table 6
Mean and Standard Deviation (SD) of students' conceptual understanding between students taught with the lecture method and the 4MAT Instructional Strategy.

Source of variation	Cognitive style	N	Mean	SD	Conceptual Standing
Pre-conceptual understanding	FI	169	14.75	3.76	Misconception Dominated
	FD	136	13.71	3.63	Misconception dominated
Post-conceptual understanding	FI	169	64.34	17.40	Fragmented understanding
	FD	136	62.62	18.18	Fragmented understanding

The result of Table 6 showed that at the pretest level, the mean pre-conceptual understanding is 14.75 for FI and 14.71 for FD, respectively. This result showed that both groups were misconception-dominated in the Radioactivity before treatment. The result also showed that the post-conceptual mean scores were 62.62 for FD and 64.34 for FI. This implies that the 4MAT instructional strategy lifted the conceptual understanding of both field-dependent and field-independent learners from a misconception-dominated level to a fragmented understanding level, with a difference in mean conceptual score. To determine whether the difference is significant, ANCOVA was employed, and the results are presented in Table 7.

Ho_3.There is no significant difference in the conceptual understanding of field-dependent and field-independent learners taught Physics using the 4MAT instructional strategy and those taught using the conventional lecture method.

To test hypothesis three, Analysis of Covariance was employed, and the result is presented in Table 7.

Table 7
Analysis of Covariance (ANCOVA) for conceptual understanding between field-dependent and field-independent learners taught with the lecture method and 4MAT instructional strategies. Dependent Variable: Post Conceptual Understanding

Source	Type III sum of squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	401.883[a]	2	200.941	.637	.530	.004
Intercept	70335.867	1	70335.867	222.955	.000	.425
Preconceptual understanding	178.206	1	178.206	.565	.453	0.002
Cognitive Styles	277.997	1	277.997	.881	.349	.003
Error	95272.235	302	315.471			
Total	1321006.000	305				
Corrected Total	95674.118	304				
a. R Squared=.004 (Adjusted R Squared=-0.002)						

Table 7 showed that F(1, 302) = 0.881, p = 0.349, which is not significant. Therefore, the null hypothesis of no significant difference between the conceptual understanding of field-dependent and field-independent learners taught using the 4MAT instructional strategy and the lecture method in Physics is accepted. From the Adjusted R Squared value, the effect of the 4MAT instructional strategy accounts for just 4% of students' cognitive styles.

Research question 4: What difference exists in the academic achievement of field-dependent and field-independent learners exposed to the 4MAT instructional strategy and those taught through the conventional lecture method in Physics?

To answer research question three, the mean and standard deviation were used, and the results are presented in Table 8.

Table 8
Mean and Standard Deviation (SD) of students' learning outcome between FI and FD among students taught with the lecture method and the 4MAT Instructional Strategy.

Source of variation	Cognitive Style	N	Mean	SD
Pretest scores	FI	169	14.15	3.83
	FD	136	13.09	4.27
Posttest scores	FI	169	62.67	16.41
	FD	136	63.87	16.25

The results of Table 8 showed that at the pretest level, the mean scores were 14.15 for FI and 13.09 for FD, respectively. The result also showed that at the posttest, scores of 63.87 for FD and 62.67 for FI were obtained. This implies that there is a difference in the learning outcomes of field-dependent and field-independent learners taught with the 4MAT instructional strategy and lecture methods in Physics.

Ho_4. There is no significant difference in the learning outcome of field-dependent and field-independent learners taught Physics using the 4MAT instructional strategy and those taught using the conventional lecture method.

To determine whether the difference is significant, ANCOVA was employed, and the results are presented in Table 9.

Table 9
Analysis of Covariance (ANCOVA) for students' learning outcome between field-dependent and field-independent learners taught with the lecture method and 4MAT instructional strategies. Dependent Variable: Post Learning Outcome

Source	Type III sum of squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	174.790[a]	2	87.395	.327	.722	.002
Intercept	92867.722	1	92867.722	347.025	.000	.535
Pretest	66.454	1	66.454	.248	.619	.001
Cognitive Styles	129.603	1	129.603	.484	.487	.002
Error	80818.607	302	267.611			
Total	1299363.000	305				
Corrected Total	80993.397	304				
b. R Squared=.004 (Adjusted R Squared=-0.002)						

Table 9 showed that F (1, 302) = 0.484, p = 0.487, which is not significant. Therefore, the null hypothesis of no significant difference in learning outcomes between field-dependent and field-independent learners taught using the 4MAT instructional strategy and the lecture method in Physics is accepted. From the Adjusted R Squared value, the effect of the 4MAT instructional strategy is negative, indicating no effect of cognitive styles on learning when the 4MAT instructional strategy is employed.

Research Question 5. How does the learning outcome of male and female learners differ when taught Physics using the 4MAT instructional strategy compared with the conventional lecture method?

To answer research question five, the mean and standard deviation were used, and the results are presented in Table 10.

Table 10
a: Mean and Standard Deviation (SD) of students' learning outcomes between male and female students taught with 4MAT Instructional Strategy.

Source of variation	Sex	N	Mean	SD
Pretest scores	Male	84	13.37	4.09
	Female	63	14.14	3.29
Posttest scores	Male	84	79.12	5.80
	Female	63	78.29	5.36

The results of Table 10a showed that at the pretest level, the mean scores were 13.37 for males and 14.14 for females. The table also showed that at the posttest, the learning outcomes were 79.12 for male students and 78.29 for female students. This implies that there is a difference in achievement between male and female learners taught with the 4MAT instructional strategy in Physics.

Table 10
b: Mean and Standard Deviation (SD) of students' learning between male and female students taught with the lecture method.

Source of variation	Sex	N	Mean	SD
Pretest scores	Male	90	13.36	4.15
	Female	68	14.03	4.55
Posttest scores	Male	90	48.69	6.58
	Female	68	48.78	7.57

The results of Table 10b showed that at the pretest level, the mean learning outcome is 13.36 for males and 14.03 for females. The result also showed that post-learning outcomes of 48.69 for male students and 48.78 for female students were obtained. This implies that there is a difference in achievement between male and female learners taught using the lecture method in Physics.

Ho_5. There is no significant difference in the learning outcome of male and female learners taught Physics using the 4MAT instructional strategy and those taught using the conventional lecture method.

To determine whether the difference is significant in the 4MAT strategy, ANCOVA was employed, and the results are presented in Table 11a.

Table 11

a: Analysis of Covariance (ANCOVA) for students' learning outcomes between male and female learners taught with 4MAT instructional strategies. Dependent Variable: posttest

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	54.980[a]	2	27.490	.870	.421	.012
Intercept	59970.148	1	59970.148	1898.922	.000	.930
Pre-experimental	29.980	1	29.980	.949	.332	.007
Sex	30.425	1	30.425	.963	.328	.007
Error	4547.686	144	31.581			
Total	916508.000	147				
Corrected Total	4602.667	146				

a. R Squared = .012 (Adjusted R Squared = − .002)

Table 11a showed that F(1, 144) = 0.963, p = 0.328, which is not significant. Therefore, the null hypothesis of no significant difference between the learning outcomes of male and female learners taught using the 4MAT instructional strategy in Physics is accepted. From the Adjusted R Squared value, the effect of the 4MAT instructional strategy on sex is negative, which establishes no effect of sex on learning outcome when the 4MAT instructional strategy is employed.

To determine whether the difference is significant in the lecture method, ANCOVA was employed, and the results are presented in Table 11b.

Table 11
b: Analysis of Covariance (ANCOVA) for students' learning outcome between male and female learners taught with the lecture Method. Dependent Variable: post-control

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	3.121[a]	2	1.561	.031	.969	.000
Intercept	32972.241	1	32972.241	664.057	.000	.811
precontrol	2.804	1	2.804	.056	.812	.000
Sex	.187	1	.187	.004	.951	.000
Error	7696.176	155	49.653			
Total	382855.000	158				
Corrected Total	7699.297	157				

a. R Squared = .000 (Adjusted R Squared = − .012)

Table 11b showed that F (1,155) = 0.004, p = 0.951, which is not significant. Therefore, the null hypothesis of no significant difference between the outcomes of male and female learners taught using the lecture method in Physics is accepted.

Research Question 6: How does the conceptual understanding of male and female learners compare when they are taught Physics using the 4MAT instructional strategy versus the conventional lecture method?

To answer research question five, the mean and standard deviation were used, and the results are presented in Table 12a.

Table 12
a: Mean and Standard Deviation (SD) of the conceptual understanding between male and female students taught with the 4MAT Instructional Strategy.

Source of variation	Sex	N	Mean	SD
Pre-Conceptual Understanding	Male	84	14.63	4.02
	Female	63	13.89	3.41
Post-Conceptual Understanding	Male	84	80.46	6.43
	Female	63	80.38	6.94

The results of Table 12a showed that at the pretest level, the mean conceptual understanding was 14.63 for males and 13.89 for females. The result also showed that post-conceptual scores of 80.46 for male

students and 80.38 for female students were obtained. This implies that there is a difference between the conceptual understanding of male and female learners taught with the 4MAT instructional strategy in Physics.

Table 12b: Mean and Standard Deviation (SD) of the conceptual understanding between male and female students taught with the lecture method.

Table 12
b: Mean and Standard Deviation (SD) of the conceptual understanding between male and female students taught with the Lecture Method.

Source of variation	Sex	N	Mean	SD
Pre-Conceptual Understanding	Male	90	14.16	3.44
	Female	68	14.40	4.05
Post-Conceptual Understanding	Male	90	47.38	6.70
	Female	68	47.72	6.48

The results of Table 12b showed that at the pretest level, the mean conceptual understanding was 14.16 for males and 14.40 for females. The result also showed that post-conceptual scores of 47.38 for male students and 47.72 for female students were obtained. This implies that there is a difference between the conceptual understanding of male and female learners taught with the lecture method in Physics.

Ho_6. There is no significant difference in the conceptual understanding of male and female learners taught Physics using the 4MAT instructional strategy and those taught using the conventional lecture method.

To determine whether the difference is significant, ANCOVA was employed, and the results are presented in Table 13.

Table 13

a: Analysis of Covariance (ANCOVA) for students' conceptual understanding between male and female learners taught with 4MAT instructional strategies. Dependent Variable: postconceptual

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	19.641[a]	2	9.821	.221	.802	.003
Intercept	59237.798	1	59237.798	1333.609	.000	.903
Preconceptual	19.391	1	19.391	.437	.510	.003
Sex	.005	1	.005	.000	.992	.000
Error	6396.359	144	44.419			
Total	957323.000	147				
Corrected Total	6416.000	146				

a. R Squared = .003 (Adjusted R Squared = − .011)

Table 13a showed that F (1,144) = 0.000, p = 0.992, which is not significant. Therefore, the null hypothesis of no significant difference between the conceptual understanding of male and female learners taught using the 4MAT instructional strategy in Physics is accepted.

Table 13

b: Analysis of Covariance (ANCOVA) for students' conceptual understanding between male and female learners taught with the Lecture Method. Dependent Variable: postconceptual

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	77.857[a]	2	38.929	.896	.410	.011
Intercept	19898.802	1	19898.802	457.780	.000	.747
Preconconceptual	73.305	1	73.305	1.686	.196	.011
Sex	3.449	1	3.449	.079	.779	.001
Error	6737.542	155	43.468			
Total	363683.000	158				
Corrected Total	6815.399	157				

a. R Squared = .011 (Adjusted R Squared = − .001)

Table 13a showed that F (1,155) = 0.079, p = 0.779 which is not significant. Therefore, the null hypothesis of no significant difference between the conceptual understanding of male and female learners taught using the lecture method in Physics is accepted.

Discussion of the Study

This study explored the effects of 4MAT instructional strategy on students' conceptual understanding, cognitive styles, and learning outcomes in secondary school radioactivity. The concept of radioactivity has been a core concept in both Physics and Chemistry in the secondary school curriculum in Nigeria. Therefore, students' conceptual knowledge of this concept will boost achievement in both subjects.

The results showed that, prior to treatment, students' pre-conceptual understanding of both the lecture method and the 4MAT instructional strategy was dominated by misconceptions regarding the concept of Radioactivity. However, the post-conceptual understanding improved from a fragmented understanding under the lecture method to a sound conceptual understanding under the 4MAT instructional strategy. This implies that both methods were capable of improving students' conceptual understanding when effectively employed in teaching and learning. The difference between the methods was tested for significance, and it was found to be significant, with the 4MAT instructional strategy showing greater conceptual understanding. This was confirmed in Table 3, with F(1, 302) = 1893.100, p = 0.000, indicating a significant effect. The 4MAT instructional strategy accounted for 86.2% of students' conceptual understanding, as indicated by the Adjusted R Squared value. This could be attributed to the activities embedded in the 4MAT strategy, which increased students' involvement in the learning process. This finding is in consonance with Nwankwo (2021), who stated that integration and functional grasp of science, especially physics ideas, are very useful components in conceptual understanding, and that students with conceptual understanding know why an idea is important and the kind of contexts in which it is useful.

Secondly, the study showed that at the pretest level, the mean scores are 13.65 for the lecture method and 13.71 for the 4MAT instructional strategy. Also, the post-test mean scores were 48.72 for the lecture method and 78.76 for 4MAT instructional strategy. A mean difference of 30.04 was obtained. This implies that students taught using 4MAT achieved greater understanding of the concept of radioactivity. This difference was found to be significant, F (1, 302) = 1688.472, p = 0.000. Also, the effect of the 4MAT instructional strategy on students' learning outcome is 84.7% according to the Adjusted R-squared value. This implies that an improved conceptual understanding translates to better learning outcomes. This finding is consistent with Quar et al. (2020), who found a significant difference between learners taught social studies using the 4MAT mode and those taught using the traditional method. Mather (2021) found a significant difference between the experimental and control groups in post-administration scores on the creative thinking test as a whole and on each of its skills, favouring the experimental group. The study aligns with Chukwuka & Ajaja (2022) and Inel (2018), who found a significant difference in achievement between students taught with the 4MAT method and those taught with the lecture method.

Also, the study agreed with Burcu & Filiz (2018) that the attainment level and mean scores favoured the experimental group taught with 4MAT integrated with an interdisciplinary structure.

Thirdly, the results showed that at the pretest level, both field-independent and field-dependent learners were misconception-dominated when taught using 4MAT instructional strategy regarding the concept of radioactivity. However, post-conceptual mean score showed that both field-dependent and field-independent learners moved from a misconception-dominated level to a fragmented understanding level, with a slight difference in mean conceptual score. Furthermore, the difference was not significant when tested with ANCOVA. Therefore, the null hypothesis of no significant difference between the conceptual understanding of field-dependent and field-independent learners taught using the 4MAT instructional strategy and the lecture method in Physics is accepted. Based on the Adjusted R Squared value, the 4MAT instructional strategy contributed only 4% to students' cognitive styles. This could be attributed to students' full participation and the varied activities they engaged in during the teaching process. This result agrees with Agboro-Eravwoke et al. (2025) and Abamba et al. (2023), who stated that Field-independent learners can be taught using a student-centred approach, in which they can work independently to a considerable extent.

Fourthly, the study examined differences in learning outcome between cognitive styles taught using the 4MAT instructional strategy and the lecture method. The results showed post-test scores of 63.87 for FD and 62.67 for FI, respectively. A slight difference between the achievement of field-dependent and field-independent learners taught with 4MAT instructional strategy and lecture methods in Physics. However, the difference was not significant, $F(1, 302) = 0.484$, $p = 0.487$. Thus, the null hypothesis of no significant difference in learning outcomes between field-dependent and field-independent learners taught using the 4MAT instructional strategy and the lecture method in Physics is accepted. From the Adjusted R Squared value, the effect of the 4MAT instructional strategy in contributing is negative, which establishes no effect of cognitive styles on achievement when the 4MAT instructional strategy is employed.

Fifthly, the results also showed improved learning outcomes in posttest scores for male and female students taught using 4MAT in Physics, with a mean difference of 0.83. When subjected to inferential statistics, the null hypothesis of no significant difference in learning outcomes between male and female learners taught using the 4MAT instructional strategy was accepted. From the Adjusted R Squared value, the effect of the 4MAT instructional strategy on sex is negative, which establishes no effect of sex on learning outcome when the 4MAT instructional strategy is employed. Also, the results showed that the learning outcomes at posttest scores of 48.69 for male students and 48.78 for female students were achieved. From the inferential statistics, no significant difference was found, $F(1, 155) = 0.004$, $p = 0.951$. Therefore, the null hypothesis of no significant difference in achievement between male and female learners taught using the 4MAT instructional strategy and the lecture method in Physics is accepted. This result is in consonance with Chukwuka & Ajaja (2022), who found that 4MAT is not sex-biased. Also, the study agrees with Dabit et al (2024), who confirmed that the 4MAT instructional method is not sex-biased in improving interest and achievement.

Furthermore, results showed that at the pre-test level, the mean conceptual understanding was 14.63 for males and 13.89 for females. The result also showed that post-conceptual scores of 80.46 for male students and 80.38 for female students were obtained. This implies that there is a difference between the conceptual understanding of male and female learners taught with the 4MAT instructional strategy in Physics. It also established that the 4MAT instructional Strategy raised both male and female participants from a misconception-dominated level to a sound conception level regarding radioactivity. Table 13a showed no significant difference in conceptual attainment between male and female students, with $F(1, 144) = 0.000$, $p = 0.992$. Therefore, the null hypothesis of no significant difference between the conceptual understanding of male and female learners taught using 4MAT instructional strategy in Physics is accepted. However, the result also showed that post-conceptual scores of 47.38 for male and 47.72 for female students were obtained when taught using the lecture method. This means that the lecture method could only raise the conceptual level of male and female students from a misconception-dominated level to a fragmented understanding. Table 13a showed no significant difference in post-conceptual attainment between male and female students, with $F(1, 155) = 0.079$, $p = 0.779$. Therefore, the null hypothesis of no significant difference between the conceptual understanding of male and female learners taught using the lecture method in Physics is accepted.

Conclusion

Based on the findings, the study concluded that there is a significant difference in the conceptual level of students taught with the 4MAT instructional strategy and the lecture method, in favour of the 4MAT instructional strategy, for the concept of radioactivity in Physics. Also, the study found a significant difference in learning outcomes between students taught with the 4MAT instructional strategy and those taught with the lecture method, in favour of the 4MAT instructional strategy. Furthermore, the study showed no significant difference between field-dependent and field-independent learners when the 4MAT instructional strategy is employed. The study also found that the 4MAT instructional strategy raised the conceptual understanding of both male and female participants from a misconception-dominated level to a sound conception level, whereas the lecture method could only raise them from a misconception-dominated level to a fragmented misconception level.

Recommendations:

Base on the findings and conclusions of this study, the following recommendations are made:

1. The study has provided statistical evidence that the 4MAT instructional strategy is significantly better at improving students' conceptual understanding and learning outcomes, irrespective of their learning style and sex, than the lecture method. Therefore, Physics teachers should adopt this method to improve students' conceptual understanding and learning outcomes in Physics.
2. Faculties of education in universities and colleges of education should ensure the inclusion of the 4MAT instructional strategy as a method of teaching Physics and other science subjects. This will

afford would-be teachers the opportunity to learn about the effective use of the method and its advantages.

Declarations

Funding Declaration

We hereby declare that this research did not receive any funding from any organisation for this research.

Competing interest

The authors declare no competing interest

Author Contribution

AUthors 1-3 designed the study, were involved in manuscript writing; author 3 and 4were involved in carrying out the validation and reliability of the instruments, author 2,3,and 4 were involved in the field work ;while authors 1 and 5 analysed the data generated

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Data Availability

The data generated and analysed during the study will be made available upon reasonable request from the corresponding author.

Ethics approval Consent to participate

Ethical approval was obtained from Delta State University Research Ethics Committee with Reference Number: Ref:DELSU/REC/2026/02. The study was reviewed and approved for execution. The committee confirms that the research design and procedures comply with the ethical standards and guidelines for educational and social science research, including the Nigerian National Code for Health Research Ethics; The Nigerian Data Protection Regulation (NDPR, 2019); and The Helsinki Declaration on National Commission for Science and Technology (NCST) guidelines; and the DELSU Research Ethics Guidelines and Procedures,

Informed Consent

was obtained from all participant above 18 in the study. For participants below 18 (minors), written informed consent were obtained from their parents/guardians for all participating secondary school learners, alongside written assent from learners themselves.

Consent to Publish

Consent to publish was also obtained from participant above 18 in the study. Participants below 18 (minors), written informed consent to participate and publish were obtained from their parents/guardians for all participating.

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