Faculty of Natural and Applied Sciences Journal of Mathematics and Science Education
Print ISSN: 2814-0885 e-ISSN: 2814-0931
www.fnasjournals.com
Volume 6; Issue 4; May 2025; Page No. 1-15.

Multiple Representations as Tools for Enhancing Students' Critical Thinking and Attitudes Towards Physics

***[1]Ogunyemi, T.G., [2]Akintoye, H.O., & [2]Owolabi, T.**
[1]Department of Natural Science Education, College of Science Education, Lagos State University of Education), Oto/Ijanikin, Lagos, Nigeria
[2]Africa Centre of Excellence for Innovative and Transformative STEM Education, Lagos State University, Ojo, 102101, Nigeria

***Corresponding author email:** ogunyemitg@lasued.edu.ng

Abstract
Especially when it comes to challenging physics subjects, the use of different representations has the potential to improve students' comprehension and meet the demands of a varied student body. This study investigates how different representations affect students' attitudes toward physics and their capacity for critical thought. Forty public senior secondary school II physics students (11th grade equivalent) make up the sample, which was drawn from two intact classes of two public senior secondary schools that were randomly chosen from public senior secondary schools in Education District V, Lagos State, South-West Nigeria, using a quasi-experimental pre-test and post-test design.The students were 15 years old on average. The Questionnaire on Students Attitude towards Physics (QOSATP) and the Physics Critical Thinking Test (PCTT) were the two tools used in the study. The instruments' reliability coefficients, as determined by the test-retest technique of analysis, were 0.82 and 0.73, respectively. The research issues were addressed using descriptive statistics (mean and standard deviation), whereas the null hypotheses were tested using inferential statistics (ANCOVA) at the.05 level of significance.
The findings demonstrated a statistically significant difference between students taught physics with multiple representation [MR] and those taught using the lecture method in terms of their critical thinking skills [F (1,37) = k97.66; p<.05] and those taught physics with multiple representation [MR] and those taught using the lecture method in terms of their attitude scores [F (1,37) = 7.00, p >.05]. Multiple representations improved students' critical thinking skills and attitude toward physics, according to the study's limitations. Among other things, it was suggested that physics instructors use this method when instructing physics in senior high schools.

Keywords: Attitude, Critical Thinking Abilities, Multiple Representations, Physics Concepts, Students

Introduction

Although the physics curriculum in Nigeria has changed over time, it still faces major obstacles. The curriculum has historically been criticized for being overly theoretical and unrelated to practical uses. Although it's necessary to comprehend the theoretical underpinnings of physics, the dearth of real-world, practical learning opportunities makes it challenging for students to relate theory to application. Due to this disconnect, there is a gap between students' knowledge of and interest in the topic (Bawan et al. , 2024). In Nigeria's upper secondary schools, physics is vital for fostering scientific literacy, critical thinking, problem-solving abilities, and an understanding of the fundamental principles of natural phenomena. Nonetheless, many students struggle greatly with learning physics. The topic covers intricate, abstract ideas that are frequently counterintuitive and challenging to comprehend. Furthermore, learning physics requires a solid understanding of mathematics. For some students, a lack of mathematical understanding might hinder their ability to learn physics. Traditional teaching methods may not effectively engage all students, resulting in boredom and disengagement. Consequently, low physics performance is a frequent problem in educational systems across the world. A student's interest in physics is greatly impacted by the resources at hand and the teachers' qualifications. To increase student participation and comprehension in physics, it suggested integrating the subject matter with their real-world experiences and using resources more effectively (Adolphus, 2019; Marshal & Conana, 2022).

Physics is regarded as the most difficult subject in science education, with fewer students choosing it over other science disciplines. Students' unfavorable perceptions of physics, which frequently originate from a lack of interest in the subject (Pongsophon,2024), are exacerbated by this attitude. In order to master physics ideas, one must possess not only a strong foundation in mathematics but also the capacity for critical thinking, problem-solving, and application of theoretical knowledge to real-world situations. In the past, physics instruction has mostly relied on written instructions and oral explanations, making it primarily text-based. Undoubtedly, physics is essential to comprehending the cosmos, and it uncovers links between seemingly unrelated phenomena while also offering potent instruments for creativity (Carlos & Calle, 2020). The role of physics is complex and may be studied through its applications in fields like medical physics, economic development, and finance (Mishkat & Intikhab, 2023). Despite its relevance, students frequently see physics as challenging due to its cumulative and abstract character, the necessity for strong mathematical abilities, and the difficulty of relating ideas to real-world circumstances. Their overall difficulty in learning the material is caused by these variables (Dumcho & Tshomo, 2023). In order to address this issue, creative teaching methods, such as numerous representations, are necessary for enhancing students' comprehension and participation.

Physics has an unusually significant role in defining what is now known as a modern society, thus it is practically necessary for science students to have a basic grasp of the subject. The study of matter and energy and their interactions in the domains of mechanics, acoustics, optics, heat, electricity, magnetism, radiation, atomic structure, and nuclear events is the knowledge that physics provides. Physics serves as the foundation of engineering, medicine, and scientific and technological progress because it is a branch of natural science (Achor et al. , 2024).

In the fields of communication, transportation, information, and healthcare, physics has several applications. The creation of devices for monitoring, measuring, regulating, and producing electricity, as well as the development of machinery and tools utilized in healthcare, military, industrial, and agricultural businesses, are all based on physics principles and knowledge. Physics instruction has centered on helping students acquire critical thinking skills, which will ultimately help them comprehend physics ideas that will lead to better academic performance (Achor et al. , 2024).

The ability of multiple representation learning to combine complementary modalities improves comprehension and performance in applications such as imagetext matching and speech recognition, which lends credence to the idea that multimodal methods can increase interaction and comprehension (Guo, 2019).

By prompting pupils to analyze and integrate data from various sources, these approaches may enhance their critical thinking skills. Furthermore, by making physics more accessible and enjoyable for a wider range of students, they can improve participation. Additionally, creative methods may assist in shifting students' attitudes about physics, encouraging favorable outlooks on the subject. Integrating multimodal representations into the instruction and learning of physics concepts can result in a more inclusive and successful learning environment that encourages critical thinking and positive attitudes towards the study of the subject. Numerous studies have demonstrated that using different representations can enhance students' retention of scientific information, critical thinking abilities, and problem-solving skills. By integrating visual, auditory, and tactile/kinesthetic learning experiences, multiple methods may help demystify complex physics concepts, making them more accessible and relevant to students. Additionally, using several representations supports the instructional goal of fostering students' critical thinking abilities. As it allows students to logically and cohesively analyze, assess, and synthesize information, critical thinking is a crucial skill in physics (Gong et al. , 2024). By encouraging students to use higher-order thinking, teaching physics through numerous representations improves their capacity for critical thinking, problem-solving, and decision-making.

Within the framework of 21st-century education, it is increasingly understood that instructional approaches must promote creativity, teamwork, communication, and critical thinking. The conventional lecture-based method of instruction physics is gradually being replaced by more interactive, student-centered methods. The use of virtual labs, multimedia resources, and other technological integrations into the classroom can give students the chance to learn about physics topics in a more interactive and engaging way. Moreover, the approach bridges the gap between theory and practice, offers students possibilities to interact with information through various media, and accommodates a wide range of learning styles. (Mayer, 2014)

Multiple representations teaching methods improve access to science subjects, especially physics, by interweaving gestures, diagrams, and bodily movements, which aid students in grasping abstract ideas such as position and displacement vectors through embodied activities (Marshall & Conana, 2022). Multiple representations incorporate several forms of media into the teaching and learning process, including visual, auditory, and textual components.

In the context of high school physics, several representations are thought to have a beneficial impact on students' opinions of the topic and to improve their critical thinking skills (Dewati et al. , 2019b; Pradhan et al. , 2016). Using a range of media—such as audio recordings, interactive simulations, and visual aids—is part of this strategy for delivering information. Students are able to engage with the material in a variety of ways by using multiple modes of representation, which caters to their individual learning styles and enhances their comprehension of the subject. Teachers must embrace various methods of presenting physics concepts to students in order to foster a deeper understanding through abstraction, extension, and relational connections between different representations (Opfermann et al. ,2017). By using multiple representations, learning physics can help students overcome their learning challenges and improve their ability to represent problems through symbolic manipulation, tables, diagrams, images, and graphs (Laras et al. , 2015). Multiple representations are helpful in the learning process since they enable learners to visualize different concepts and link them to several equations that are accurate for solving problems (Dewati et al. , 2019a, 2019b). Multiple representations will help students enhance their abilities in the creation of complex scientific ideas and knowledge (Dewati et al. ,2019a).

Attitude toward Physics in this study is defined as the student's emotions, opinions, and values regarding the subject, as expressed through their like or dislike, as well as their favorable or unfavorable reactions to Physics ideas. Having a positive outlook fosters a positive sense of self, enhances one's health, opens doors, and helps one make friends. People with a positive attitude are more likely to be successful in achieving their goals and seem content by choice, regardless of their circumstances. In contrast, people with a negative attitude tend to lament that nothing good ever happens in their lives, view everything as bad, and things get worse (Burke et al. , 2022). One of the most significant variables in science students' learning of physics is attitude (Ibrahim et al. , 2019). Attitude is a learning scale that determines the best way to summon students to class. Attitude is a person's feeling, attitude, or behavior toward something. It may be viewed as a supporting tool that notifies teachers, legislators, and scholars about the requirements for sparking interest in learning a specific topic, such as physics (Kanyesigye et al. , 2022; Ishrat et al. , 2020). Attitude is an internal state that affects students' choices or decisions to act in a certain way under certain circumstances. It is a predisposition to act in a particular way, according to attitude.

Students' interest, drive, and perceived relevance of the subject are crucial factors in promoting long-term engagement with the subject and real-world experiences. These factors often define students' attitudes toward learning physics ideas. By offering a wide range of stimuli that may appeal to different learning styles, physics can be made more interesting through the use of multiple representations. According to research, employing interactive components (such animations and simulations) promotes active learning, which in turn may enhance students' attitudes toward learning physics. In their study, Sahin and Yasar (2016) discovered that multimedia resources, such as simulations and animations, increased students' interest in learning physics by making the concepts more relatable and enjoyable. Students were able to appreciate the real-world uses of physics ideas thanks to their capacity to engage with dynamic depictions of physical events, which in turn resulted in a more favorable outlook. Ogunleye and Baba (2011) also discovered that pupils who used computer simulations were more interested in physics and were less likely to find the subject challenging. This result implies that complex subjects may be demystified by multimodal representations, making them more approachable and interesting for students.

Students' capacity for critical thinking about physics ideas is another essential learning attribute that science students should acquire or have after being exposed to some of the 21st-century teaching and learning approaches. The importance of critical thinking skills for learning and comprehending complex ideas, as well as for coping with the demanding and constantly changing external world, has been emphasized in several studies. Critical thinking, according to Ahove (2020), is the active and skilled conceptualization, application, analysis, synthesis, and/or evaluation of data obtained from or produced by observation, experience, reflection, reasoning, or communication as a foundation for faith or action. Critical thinking is the capacity for fact analysis and judgment formation. It's a kind of emotional intelligence. Someone with critical thinking abilities is able to maintain clarity and rationality in challenging circumstances. It gives them the ability to make decisions and solve problems more successfully. The capacity to think logically and methodically in order to comprehend the links between facts can also be used to define it. It aids in making informed decisions about what to believe. In other words, it's "thinking about thinking," which means identifying, analyzing, and correcting flaws in our thought processes.

Cite this article as:
Ogunyemi, T. G., Akintoye, H. O., & Owolabi, T. (2025). Multiple representations as tools for enhancing students' critical thinking and attitudes towards physics. *FNAS Journal of Mathematics and Science Education*, *6*(4), 1-15

In any profession one chooses to pursue, critical thinking is always considered necessary for a positive outcome since it involves analyzing problems to make sound decisions. Because it allows students to think deeply, which results in academic success, critical thinking ability has an impact on their learning process (Akpur, 2020; Pozhham et al. , 2019). Every aspect of life places a high value on critical thinking because of its problem-solving capabilities, which lead to positive developments.

In order to confidently use classroom problem-solving techniques in real-world scenarios, physics students must be able to comprehend a variety of physics principles, laws, and theories. In order to support students in accomplishing these objectives, project-based learning, collaborative learning, and the guided discovery approach must be incorporated into the teaching method. According to Ahove (2020), critical thinking is a talent that all Africans and teachers need in order to participate effectively in the creative and dynamic industrial world. In the Physics classroom, several teaching methods have been employed for instructional or research reasons in order to help students overcome these difficulties. Still, kids' grasp of complex physics concepts, their approach to learning physics, and their critical thinking skills in tackling tough physics problems were still disheartening. This necessitates the use of twenty-first century instructional approaches like multimodal representation (Pascasie et al. , 2022; Merta et al. , 2022).

Problem-solving, where students must use conceptual understanding to evaluate and address complicated challenges, is frequently a part of critical thinking in physics. By presenting various perspectives on the same physical idea, multiple representations can aid students in gaining a deeper understanding of the topic, which in turn improves their capacity for problem-solving. Students who employed interactive visualizations, such as simulations of physical systems, did better in problem-solving activities, as demonstrated by Kaufman et al. (2020). Students' ability to think critically and solve problems was enhanced by the visual feedback they received from these representations, which enabled them to evaluate their theories and improve their grasp of the subject matter. Palanisamy,2020; Rau,2017; Grossman, & Layne,2018). Chang & Tseng (2013) also discovered that pupils who interacted with dynamic simulations in physics were more adept at applying their theoretical knowledge to real-world situations. Students were able to experiment and see the results through the multimodal representations, which fostered critical analysis and reflective thought.

Despite the significant roles of attitude and critical thinking skills in improving physics learning outcomes, students continue to perform poorly in the course year after year (WAEC chief examiners' reports, 2015, 2017, 2020, and 2023). The difficulty of the topic is a major issue, and there are numerous other contributing causes for these subpar results. Physics is a difficult and abstract field that requires advanced mathematical reasoning, spatial understanding, and critical thinking. These cognitive needs are difficult for many students, especially when they are faced with subjects like energy conservation, forces, and wave phenomena (Khalili, 2016).

Theoretical Review

Vygotsky's Constructivist Learning Theory and Bandura's Social Learning Theory serve as the foundation for this work. According to Constructivist theory, students actively create their knowledge via social interaction and environmental interaction. This theory is supported by several representations that offer a variety of methods for comprehending complicated ideas. Students actively engage with various modalities (such as hands-on experiments and simulations) to build their understanding in ways that are consistent with their prior knowledge and experiences (Chen et al. , 2020). Multiple representations promote higher-order cognitive processes like analysis, synthesis, and assessment, all of which are necessary for critical thinking. By emphasizing student agency and relevance, constructivist methods have a beneficial impact on attitudes toward physics and encourage intrinsic drive to learn.

The role of observational learning, imitation, and modeling in the learning process is highlighted by Social Learning Theory. In physics classes, several representations, such videos or simulations, serve as models for students to observe and learn from. By watching demonstrations of physical phenomena or professionals solving problems, students replicate their thoughts and problem-solving methods. Students' critical thinking is improved by seeing different approaches and perspectives (Abrami et al. , 2015). Interactive simulations let you experiment and reflect, which helps you improve your critical thinking abilities. According to Bandura, pupils are more prone to acquire positive attitudes if they see examples of successful models. Multiple resources demonstrating successful problem-solving experiences make physics accessible and achievable, which promotes a positive attitude. These ideas offer a framework for understanding how various representations might be used to maximize learning in physics, where both conceptual and spatial reasoning are essential. Students' comprehension of complex topics is improved, their attitudes toward the subject are enhanced, and their capacity for critical thinking is developed through the use of several methods.

In instructional materials, an excellent multiple representation can be shown. Because they facilitate students' development of competencies, teaching materials are crucial to the implementation of learning in schools (Li, 2020; Philippe et al., 2020). This could be accomplished by physics teachers prioritizing the use of both textbooks and workbooks to teach students physics concepts. This way, students can have time to practice and learn physics concepts from their workbooks, which contain multiple representations that can foster a positive attitude and enhance critical thinking abilities. One type of instructional resource used in learning exercises is a workbook. Workbooks encourage students to actively expand their knowledge, which helps them think more critically about the content they already know. In order to process their knowledge, pupils must be able to think critically, logically, and methodically. Students must be able to generate and master several representations (presentations) or multi-representational abilities in order to solve problems that are based on the content found in educational materials (Fauziah & Raisal, 2022; Munfaridah et al., 2021). With the aid of a workbook, kids can learn on their own. He actively learns without the greatest amount of guidance from an instructor. Teaching materials workbooks minimize learning-oriented instructor centers, according to prior research; students are more active in their learning and more focused on discovering topics (Liana et al.,2023). In addition, a workbook can help students reach their learning objective of developing their intellectual capacity (Suryawati & Osman 2017; Nickerson et al 2014; Wankat & Oreovicz, 2015). The framework for teaching physics, critical thinking, and various representation is depicted in Figure 1 below.

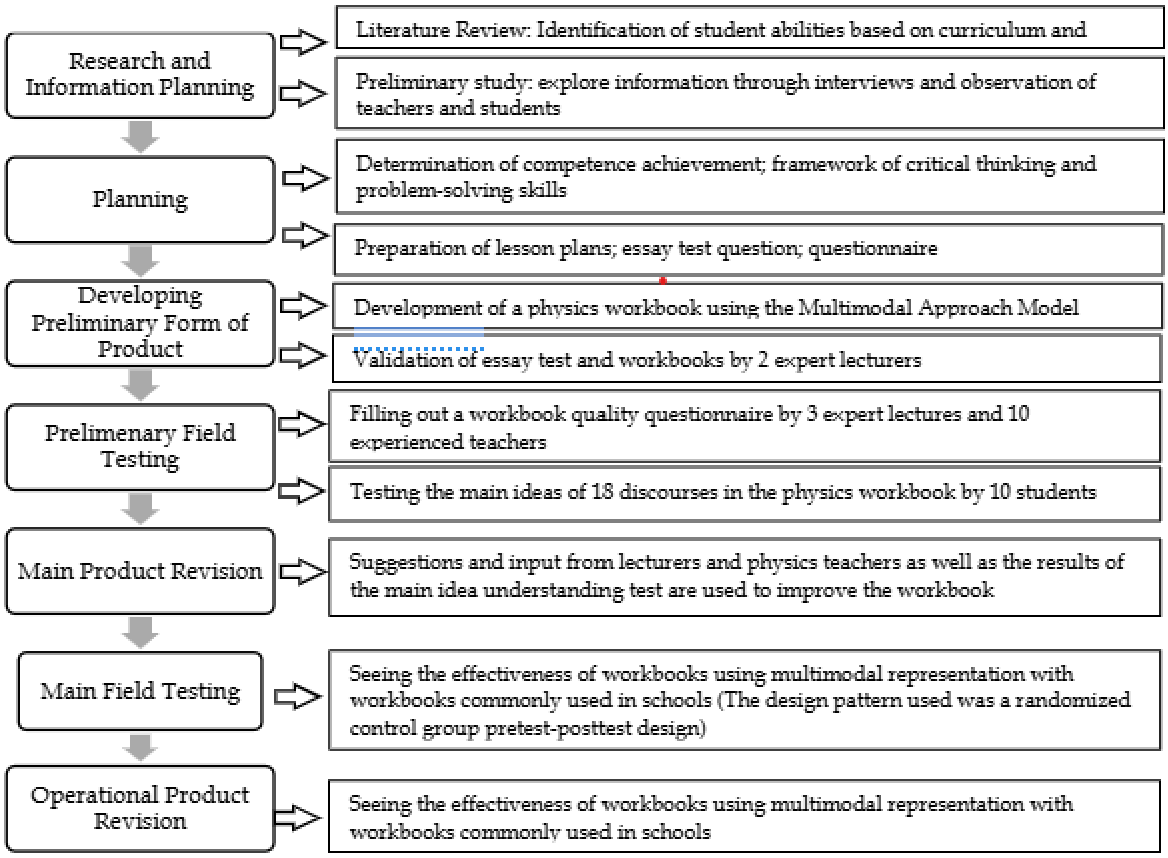

Fig 1: Research Framework Metta L, Sinaga. P,&Emmilianur (2017) Physics Workbook using Multiple Representation

Statement of Problem

Although physics has many potential advantages, such as advances in science and technology, the academic world has become increasingly worried about the methods used by instructors to teach the subject. Inadequate training for teachers in the use of proper instructional methods has been shown by research to lead to poor student performance in physics and a lack of critical thinking necessary for applying knowledge in problem-solving

Cite this article as:
Ogunyemi, T. G., Akintoye, H. O., & Owolabi, T. (2025). Multiple representations as tools for enhancing students' critical thinking and attitudes towards physics. *FNAS Journal of Mathematics and Science Education*, *6*(4), 1-15

situations (Browne & Keeley, 2010; Brookfield, 2012; Achor, 2020). Over the years, students' performance in physics has not been promising in external exams. For both the WASSCE and NECO exams, the trend is the same as in secondary schools in all Nigerian states (Achor, 2024). Furthermore, traditional teaching methods, which are often teacher-centered and based on rote memorization, do not adequately engage students or foster active learning. Due to their inability to accommodate the varied learning styles of students, these approaches tend to foster a disengaged approach to the subject (Gong et al. , 2024). The current teaching methods also restrict pupils' ability to acquire crucial skills like problem-solving, critical thinking, and analytical reasoning, all of which are necessary for excelling in physics. Prior research has demonstrated how to enhance students' critical thinking skills and attitudes when learning Physics topics. (Bawan et al. , 2024; Gong et al. , 2024).

This study aims to fill the gaps in students' negative attitudes and poor critical thinking skills in learning physics concepts by examining the impact of multimodal representations on the attitudes and critical thinking skills of senior secondary school students in physics. The study was guided by **two research questions:**

1. Will the critical thinking skills of physics students differ noticeably?

Which group of students was taught physics topics through the lecture method and which group was taught using multiple representations [MR]?

2. Is there a noticeable difference in the attitudes of physics students who are instructed using the lecture method versus those who are taught using multiple representations (MR)?

Research Hypotheses

1. There will be no statistically significant difference in the critical thinking skills of students who learn Physics concepts through the use of multiple representations [MR] versus those who are taught using the lecture method?

2. There will be no statistically significant difference between in the attitudes of physics students who are taught using the lecture method and those who are taught using several representations (MR)?

Material and Methods

Design

The design of the investigation was quasi-experimental. the pre-test, post-test, and control groups' quasi-experimental design. While the control group used the conventional lecture method, the experimental group used a multimodal approach. Pre-test and post-test treatments were administered to both the experimental and control groups. The many representations strategy is the independent variable, and the attitude toward physics and the physics critical thinking assessments are the dependent factors.

Sample

Forty senior secondary school (SS two) physics students from Education District V in Lagos State made up the study sample. The experimental group (Multiple Representations, or MR) consisted of 19 students, while the control group consisted of 21 students. All physics students in Lagos State's Senior Secondary School (SS 2) made up the study's population.

Instrumentation

The Physics Critical Thinking Test (PCTT) and the Questionnaire on Students Attitude Toward Physics (QOSATP) are the two instruments used in this study. West African Examinations Council (WAEC) previous questions from 2018–2024 were used to create the Physics Critical Thinking Test (PCTT), which is based on the first term SS II scheme of work's ideas of force and vector equilibrium. Twenty essay questions taken from WAEC past exam exams from 2018 to 2024 made up the instrument. statistics of the respondents, whereas part 2 of 20 questions that addressed topics such as the abstract nature of physics, critical thinking skills, student attitudes toward physics, and teaching strategies, among other things. Strongly Agreed (SA=4), Agreed (A=3), Disagreed (D=2), and Strongly Disagreed (SD=1) were the four rating scales used to arrange the question components.It was anticipated that the past questions would have been validated prior to use because the Physics Critical Thinking Test (PCTT) was taken from West African Examinations Council (WAEC) past questions (2018–2024). Nevertheless, the instrument was reviewed and adjusted by experts in the field of physics education. The Questionnaire on Students Attitude Toward Physics (QOSATP) was subjected to the opinions of physics majors and professionals in test measurement and evaluation to guarantee its face validity and substance. After the instruments were pilot tested and the data was subjected to test-retest analysis using K-21 with SPSS, the PCTT and QOSATP were shown to have reliability coefficients of 0.82 and 0.73, respectively, using Cronbach alpha with SPSS. These numbers demonstrate the dependability of the two instruments because they fall within the recommended range of 0.70 to 0.80

Ethical Procedure

In order to conduct the study, the researcher obtained oral agreement from the students via their physics and class professors, as well as approval from the Lagos State Ministry of Education, the principals of the schools, department heads, and subject teachers. To make sure that everyone who participated in the research study did so voluntarily, measures were taken before the instruments were administered.

Treatment Procedure

To ascertain the students' prior understanding of the subjects of equilibrium of forces and vectors, a pre-test was given to both the experimental and control groups. This took a week, after which the two groups received their lessons. Multiple Representations (MR) was the treatment used for the experimental group. The chosen school received the treatment for two weeks. During the same two weeks, the selected school also used the conventional lecture approach as a control. The instructional guide created for teaching equilibrium of forces and vectors was used to conduct the treatment. The experimental group used the MR technique to learn about the equilibrium of forces and vectors from the trained research assistants. The experimental group's students were required to complete every task outlined in the teachers' instructional manual.

Conversely, the experimental group's lesson plans were used to teach the control group utilizing the conventional lecture method. The instructor used the chalk-and-talk method to convey the concepts, reviewed the earlier courses, introduced the new subject, and clarified the important terms. Students were not permitted to study in groups or be exposed to various teaching modalities, as was the case during experiments with the experimental group, and there was no opportunity for student participation in the learning process because the instructor concentrated more on providing notes when using the traditional lecture method. During the same two weeks, the students in these groups received concurrent instruction.

Following instruction, the two groups were given the post-tests. After class, the researchers were able to evaluate the students' attitudes and critical thinking skills thanks to this examination.

Analysis

Quantitative data analysis was applied to the QOSATP and PCTT data gathered. The pre-test and post-test data collected from the control and quasi-experimental groups were analyzed using inferential statistics. IBM-SPSS version 23 was used to perform Analysis of Covariance (ANCOVA) on the obtained data, and the mean and standard deviation were used to descriptively assess the study topics. Percentages were used to illustrate the statistical analysis of the data collected for this study regarding the respondents' distribution by gender and teaching techniques. The study topics were addressed using descriptive statistics (mean and standard deviation), and the null hypotheses were examined using analysis of covariance (ANCOVA). The mean scores were represented graphically, and parametric assumptions were tested. Since there was no random assignment to the experimental and control groups, ANCOVA was the proper statistic to apply for testing the null hypotheses. To ensure that the data met the requirements for ANCOVA testing, tests for normality and homogeneity of variance were performed prior to the data sets being entered into the ANCOVA equation. Achievement and attitude statistics were not statistically significant. The data passed the normalcy test of assumption because it suggests that the sample from which the population was taken is not abnormal. the results of Levene's Test of Equality of Error Variances, which determines if the dependent variables' variances are the same for each group. With a Sig. Value of 0.306 and a Levene statistic of 1.078 for critical thinking, there is no discernible difference in variances between the groups. With a Sig. Value of 0.236 and a Levene statistic of 1.452 for attitude, both of which are higher than 0.05, it appears that the groups' variances are equal. As a result, both tests demonstrate that attitude and critical thinking satisfy the assumption of equal variances.

Results

Descriptive statistics of mean and standard deviation were applied to the study topics. Analysis of covariance was performed on the data gathered in order to evaluate the hypotheses (ANCOVA).
Research Question 1: Will physics students who are taught using multiple representations (MR) and those who are taught using the lecture approach differ significantly in their capacity for critical thought?

Cite this article as:
Ogunyemi, T. G., Akintoye, H. O., & Owolabi, T. (2025). Multiple representations as tools for enhancing students' critical thinking and attitudes towards physics. *FNAS Journal of Mathematics and Science Education, 6*(4), 1-15

Table 1: Mean and Standard Deviation demonstrating Physics students' post-test critical thinking skills Physics ideas were taught to students using both the lecture technique and multiple representation [MR].

GROUP	Mean	Std. Deviation	N
Multiple Representations [MR]	69.21	11.45	19
Lecture Method	36.38	19.87	21
Total	51.98	23.21	40

According to Table 1's data, students who were taught physics using multiple representations (MR) scored higher on the post-test (69.21) than those who were taught through lectures (mean score of 36.38). This suggests that the MR teaching approach may have had a greater favorable impact on students' critical thinking skills than the conventional lecture format. Additionally, the MR group's standard deviation (11.45) indicates that the scores were comparatively grouped around the mean, indicating that the kids performed consistently. The lecture technique group's standard deviation (19.87), on the other hand, shows more variation in students' performance and less consistency in their critical thinking results. The first hypothesis was examined using ANCOVA to see if the observed difference in mean scores was statistically significant after controlling for other variables, even if the descriptive statistics indicated that MR was more effective.

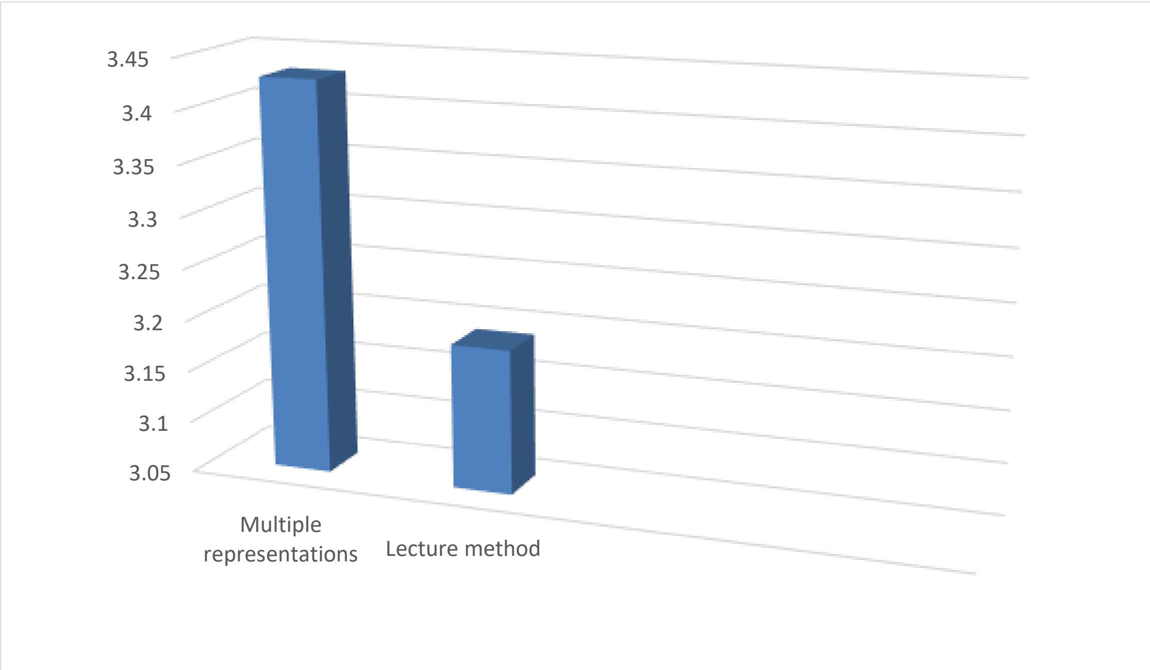

Figure 1: Bar chart representation of attitude scores of students in multimodal representation [MMR] and lecture method physic classroom

Hypothesis 1

The critical thinking skills of students taught physics ideas through the multiple representations [MR] technique and those taught through the lecture method do not differ statistically significantly.

Table 2: ANCOVA demonstrating how multiple representation [MR] affects senior secondary school pupils' capacity for physics critical thought

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	16514.875[a]	2	8257.438	68.014	.000	.786
Intercept	14998.418	1	14998.418	123.537	.000	.770
PRETEST	5764.011	1	5764.011	47.476	.000	.562
GROUP	11857.265	1	11857.265	97.665	.000	.725
Error	4492.100	37	121.408			
Total	129063.000	40				
Corrected Total	21006.975	39				

a. R Squared = .786 (Adjusted R Squared = .775)

According to table 2 above, the ANCOVA test evaluating the impact of MR on physics students' critical thinking skills revealed a significant difference between the two groups before treatment [F (1,37) =.47.47; p <.05] for the pre-test. Additionally, the table demonstrates that students who were taught physics using the lecture technique and those who were taught physics using multiple representations [MR] had significantly different critical thinking ability ratings [F (1,37) = 97.66; p<.05]. The method's partial eta squared indicates that the difference in the two groups' scores for critical thinking ability was influenced by the teaching strategy by 72.5%.

Research Question 2: Will the attitudes of physics students who are taught using multiple representations (MR) and those who are taught using the lecture approach differ significantly?

Table 3 : Displays the mean and standard deviation of the post-test attitude scores of physics students who were taught the subject through lectures and multiple representations [MR].

Group	**Mean**	**Std. Deviation**	**N**
Multiple Representations[MR]	3.43	.25	19
Lecture Method	3.19	.37	21
Total	3.31	.34	40

Students who were taught physics using multiple representations (MR) had a higher post-test attitude mean score (3.43) than those who were taught through lectures, with a mean score of 3.19, according to Table 2's data. This suggests that compared to the conventional lecture style, the MR approach might have promoted a more positive attitude toward physics. The MR group's standard deviation (.25) indicates that there was little variation in the pupils' attitude scores. The lecture technique group, on the other hand, showed greater variability in their attitude scores, as seen by their higher standard deviation (.37). As can be seen below, ANCOVA was used to test hypothesis two to determine whether the difference was significant.

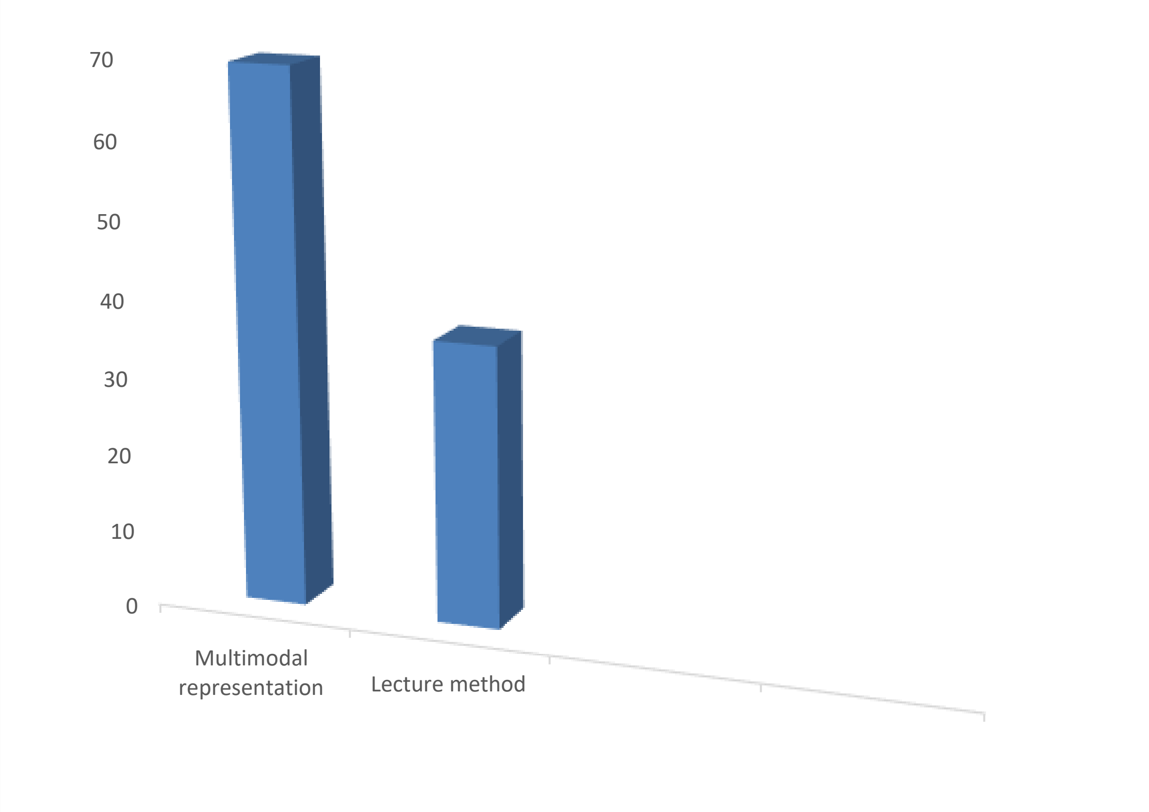

Figure 2: Bar chart representation of attitude scores of students in multiple representations [MR] and lecture method physic classroom

Hypothesis 2
Students' attitudes about physics ideas taught using multiple representations [MR] and those taught through lectures will not differ statistically significantly.
Table 4: ANCOVA demonstrating how senior secondary school pupils' attitudes toward physics are impacted by multiple representations [MMR]

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.813[a]	2	.406	4.212	.022	.185
Intercept	.354	1	.354	3.672	.063	.090
Pretest_Attitude	.280	1	.280	2.903	.097	.073
GROUP	.676	1	.676	7.002	.012	.159
Error	3.570	37	.096			
Total	441.304	40				
Corrected Total	4.383	39				

a. R Squared = .185 (Adjusted R Squared = .141)

As can be seen in table 2 above, the pre-test's F value [F (1,37) = 2.90; p >.05] indicates that there was no discernible change in the attitudes of the two groups before the treatment. On the other hand, the table demonstrates that the attitude scores of students who were taught physics using the lecture technique and those who were taught physics using multiple representations [MR] differed significantly [F (1,37) = 7.00; p<.05]. The approach taken to teach the topic had a 15.9% impact on the difference in the attitude scores of the two groups, according to the partial eta squared linked with the method.

Discussion

Table 2 and Figure 2 above demonstrated that students who were taught physics by multiple representation (MR) had a higher post-test mean score (69.21) than those who were taught through lecture, with the latter group achieving a mean score of 36.38. This suggests that the MR teaching approach may have had a greater favorable impact on students' critical thinking skills than the conventional lecture format. Additionally, the MR group's standard deviation (11.45) indicates that the scores were comparatively grouped around the mean, indicating that the kids performed consistently. The lecture technique group's standard deviation (19.87), on the other hand, shows more variation in students' performance and less consistency in their critical thinking results. The first hypothesis was examined using ANCOVA to see if the observed difference in mean scores was statistically significant after controlling for other variables, even if the descriptive statistics indicated that MR was more effective. In light of these findings, existing research indicates that students' comprehension and retention are enhanced by diverse representations (Mayer, 2009). For example, Ainsworth (2006) emphasizes how students can better comprehend and resolve physics problems when text and graphics are combined. According to the analysis of table 1 above, there was a statistically significant difference between the critical thinking skills of students who were taught physics concepts through MR and those who were taught through lectures. A study by O'Halloran et al. (2017) indicated that students' critical thinking abilities in science were enhanced by various representations learning experiences, which supports this finding. Students' representation skills are improved when multi-representation is used in physics instruction. This enables them to formulate information, generate new representations, and solve problems, which makes classrooms more engaging and helps students make connections between previously learned material and new information (Winda et al, 2019). These resources can help make difficult concepts more understandable and less frightening by graphically depicting them. According to Zheng & Warschauer (2015), students who utilized multimedia learning resources in physics expressed more assurance in their comprehension of the material. These resources helped students close the gap between academic knowledge and real-world application by giving them interactive, visual representations of phenomena. Students' mental grasp of physics ideas can be greatly enhanced by using multiple representations, which is an effective learning method (Treagust et al, 2018). Students' mental grasp of physics ideas can be greatly enhanced by using multiple representations, which is an effective learning method (Treagust et al, 2018). Students will become more proficient in developing complex knowledge and scientific concepts with the use of multiple representations (Dewati et al., 2019a). Multiple representations can take many different forms, such as mathematical, verbal or linguistic, visual, pictorial, or diagrammatic. It indicates that students possess different representational abilities when they can use a variety of symbols to describe physics concepts (Hung & Wu, 2018). Students who are able to convert spoken problems into diagrams are more adept at solving difficulties than those who are not (De Cock, 2012; Kohl et al., 2007). According to Al-Jarf (2024), multimodal learning enables students to communicate their ideas through a variety of media, such as spoken presentations, visual aids, and writing. Through a variety of activities including digital storytelling and group projects, this method stimulates several sensory systems while encouraging creativity and improving communication abilities. Because a subject given using various representations can promote deep knowledge so that students can acquire a complete understanding of the associated concepts, multiple representations have proven crucial in helping science students develop a better understanding. According to Masrifah et al. (2020), the use of multiple representations allows students to perceive and apply difficult concepts in a way that facilitates effective instruction. Given that many representations emphasize conceptual comprehension and qualitative reasoning in learning, it is clear that they are highly beneficial for usage in conceptual learning, such as in physics. An successful learning process could result from a many representations approach to teaching and learning.

In physics classes, a variety of semiotic modes facilitate student involvement by allowing students to express their thoughts, relate new ideas to what they already know, and participate more fully with the material, all of which improve the learning process (Danielsson & Uddling, 2022). Students build concepts in these classrooms based on their imaginations of the world around them, then incorporate these concepts into the learning process to help them make physics applicable to their everyday lives. According to Orulebaja et al. (2020), the many representations learning technique is one of the primary steps students need to take in order to improve their problem-solving skills in physics. representations, they are able to outperform kids who are taught problem-solving techniques in a typical manner, Jatmiko et al. (2024) also confirmed that students improve their problem-solving skills when they use a variety of representations. More precisely, pupils can outperform those who acquire problem-solving techniques the old-fashioned way when they learn to solve issues using many representations.

Additionally, the results shown in Table 2 showed that the attitude scores of students taught physics using the lecture technique and those taught physics using multiple representations [MR] differed statistically significantly [$F(1,37) = .09$; $p < .05$]. Mayer's (2007) research, which found that students who used multimedia resources to study had greater motivation and interest in the subject than those who used traditional text-based approaches, corroborated this finding. Students that used multimedia tools to learn expressed greater motivation and interest in the subject, according to Brutman et al. (2024). More favorable attitudes about physics can result from the use of various representations, which can make learning more interesting and pleasurable (Mayer, 2009). In a similar vein, Iqbal et al. (2023) found that a learner's attitudes regarding school were a crucial element in predicting their academic success. Therefore, the study's conclusion is that while a negative attitude leads to negative outcomes, a positive attitude produces favorable outcomes. Students' attitudes about physics are one of the most significant aspects that can be linked to their learning of the subject (Diyana et al., 2024). It is not a given that the lecture style, which is frequently employed in physics instruction, may be the cause of students' attitudes and the ensuing subpar performance in the subject. The way that pupils are taught has a big impact on what they learn (Abdulhamid, 2013). Therefore, since unfavorable attitudes about a lesson or a subject matter make learning more difficult, it becomes essential to improve pupils' negative attitudes toward physics.

Implications of this study

Although some scientific professors and students believe that physics is inherently hard to teach or comprehend, this does not negate the subject's significance as a foundational discipline. Physics is a senior secondary school subject that aims to give science students the positive attitude, values, abilities, and foundational knowledge needed for any human society to grow scientifically and technologically.

This subject offers students the chance to grow holistically by giving them the academic knowledge and critical life skills they need to succeed in a world that is becoming more complex. Students are better equipped to face obstacles, make wise judgments, and make significant contributions to society when they are encouraged to think critically, solve problems, and have a positive attitude toward physics.

Students will be able to learn how to translate spoken instructions into visual, formular, mathematical, and symbolic representations through this type of study that uses multimodal representations. This will encourage more positive interactions between students and the learning materials, a sort of shift from teacher-centered to student-centered interactions, and active student learning of the desired. In order to accomplish the objectives of physics education, the study will be able to determine how MR affects students' attitudes toward learning the subject and their capacity for critical thought in it. Appropriate recommendations will be made to other researchers, physics education stakeholders, and pertinent governmental organizations.

Conclusion

According to the study, MR instruction outperforms traditional lecture instruction in terms of student learning. The critical thinking ability scores of students who were taught physics using the lecture technique and those who were taught physics using multiple representations [MR] differed statistically significantly [$F(1,37) = 97.66$; $p<.05$]. Additionally, the study revealed a statistically significant difference in the attitude scores of students who were taught physics using the lecture technique versus those who were taught physics using multiple representations [MR] [$F(1,37) =.09$; $p<.05$].

It was determined and suggested that promoting the use of multimodal representations in physics instruction will improve students' critical thinking abilities, attitude toward physics, and active engagement in the subject.

Recommendations

In order to improve students' performance, engagement, understanding, and attitude toward physics, it was determined that the use of various representations should be promoted in physics instruction. However, this study was restricted to specified concepts in physics and did not take into account other 21st century methods or their interacting effect between them and numerous representations.

References

Abdulhamid, A. (2013). Effects of teaching methods on retention of agricultural science knowledge in senior secondary schools of Bauchi local government area, Nigeria. *International Journal of Science and Technology*, 4(4), 63–69.

Abrami, P. C., Bernard, R. M., Borokhovski, E., Waddington, D. I., Wade, C. A., & Persson, T. (2015). Strategies for teaching students to think critically: A meta-analysis. *Review of Educational Research*, 85(2), 275–314.

Achor, E. E., Jack, G. U., & Uzomah, T. N. (2024). Enhancing students' critical thinking in physics using graphic organizer enhanced and context-based learning strategies. *Journal of Research in Science and Mathematics Education* (J-RSME), 3(1), 1–20.

Ahove, M. A. (2020). 21st century skill. Africa Centre for Innovative and Transformative STEM Education (LASU ACEITSE).

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction,* 16(3), 183–198.

Akpur, U. (2020). Critical, reflective, creative thinking and their reflections on academic achievement. *Thinking Skills and Creativity*, 37, 100683. https://doi.org/10.1016/j.tsc.2020.100683

Anna, B., Tarasenko, K. V., Polyezhayev, Y., Matsegora, I. L., & Rukolyanska, N. (2024). Multimedia resources as a factor of increasing students' motivation in learning foreign languages. Conhecimento & Diversidade, 16(41), 546–567. https://doi.org/10.18316/rcd.v16i41.11545

Bandura, A. (1977). Social learning theory. Prentice-Hall.

Bawan, A. M., Kamgba, F. A., & Obi, D. O. (2024). Refocusing the teaching of physics for the technological development of Nigeria. British Journal of Education, Learning and Development Psychology, 7(3), 14–20. https://doi.org/10.52589/bjeldp-raj4ekc5

Brookfield, S. (2012). *Teaching for critical thinking*: Tools and techniques to help students question their assumptions. Jossey-Bass.

Browne, M., & Keeley, S. (2010). Asking the right questions: A guide to critical thinking (9th ed.). Pearson.

Carlos, I. C. (2020). Superstrings and other things: A guide to physics.

Chang, C. K., & Tseng, K. H. (2013). The effects of dynamic computer-based simulations on physics problem solving. Educational Technology & Society, 16(4), 115–127.

Chen, J. C., Huang, Y., Lin, K. Y., Chang, Y. S., Lin, H. C., Lin, C. Y., & Hsiao, H. S. (2020). Developing a hands-on activity using virtual reality to help students learn by doing. *Journal of Computer Assisted Learning*, 36(1), 46–60.

De Cock, M. (2012). Representation use and strategy choice in physics problem solving. *Physical Review Special Topics Physics Education Research*, 8(2), 020117.

Dewati, M., Suparmi, A., Sunarno, W., Sukarmin, & Cari, C. (2019a). Preservice teachers' concept understanding profile about DC circuit based on multiple representation. *AIP Conference Proceedings*, 2202, 020064. https://doi.org/10.1063/1.5141674

Dewati, M., Suparmi, A., Sunarno, W., Sukarmin, S., & Cari, C. (2019b). Implementasi multiple representation pada rangkaian listrik DC sebagai upaya meningkatkan problem solving skills. Prosiding SNFA (*Seminar Nasional Fisika dan Aplikasinya*), 4, 140.

Dumcho, W., & Tshomo, S. (2023). Exploring students' perceived difficulties of learning physics. Освіта, інноватика, практика, 6. https://doi.org/10.17102/eip.6.2023.03

Fauziah, R. N., & Raisal, A. Y. (2022). Development of multiple representation-based e-modules to improve abstract thinking skills in physics of high school students. *Journal Pendidikan Fisika*, 11, 122–127.

Federal Government of Nigeria. (2013). National policy on education. NERDC Press.

Grossman, H. M., & Layne, C. M. (2018). Using heuristic tools to improve critical thinking in a problem-based learning curriculum. In *41st Annual Proceedings* (Vol. 2, pp. 270–277).

Hung, C., & Wu, H. (2018). Tenth graders' problem-solving performance, self-efficacy, and perceptions of physics problems with different representational formats. *Physical Review Physics Education Research*, 14(2).

Ibrahim, N., Zakiang, M. A., & Damio, S. M. (2019). Attitude in learning physics among form four students. *Social and Management Research Journal*, 16(2), 21–42.

Ishrat, A., Malik, R., Baba, S. H., Bhat, B. A., Tariq, S. T. A, Rather, M. A., & Islam, T. (2020). Socio-economic correlates of attitude of youth of fishing communities towards fishing occupation in Kashmir Valley. International Journal of Current Microbiology and Applied Sciences, 9(10), 172–178. https://doi.org/10.20546/ijcmas.2020.910.022

Jatmiko B., Kurnia, B., Hanandita, V., Saphira, V., & Siswanto, J. (2024). Investigation-based multiple representation online model to improve students' problem-solving skills. Perspektivy Nauki i Obrazovaniâ, 69(3), 621–636. https://doi.org/10.32744/pse.2024.3.38

Jolanta, B., Dunne, P. J., Meehan, T., O'Boyle, C. A., & van Nieuwerburgh, C. (2022). Positive health. Routledge. https://doi.org/10.4324/9781003279594

Kanyesigye, S. T., Uwamahoro, J., & Kemeza, I. (2022). Effect of problem-based learning on students' attitude towards learning physics: A cohort study. F1000Research, 11. https://doi.org/10.12688/*F1000Research*.123456.1

Kaufman, D. B. (2020). Effects of interactive visualizations on high school students' problem-solving abilities in physics. Physics Education Research, 15(2), 34–45.

Khalili, P. (2016). Mathematical needs in the physics classroom.

Kohl, P. B., Rosengrant, D., & Finkelstein, N. D. (2007). Strongly and weakly directed approaches to teaching multiple representation use in physics. *Physical Review Special Topics—Physics Education Research*, 3(1), 010108.

Kristina, D., & Uddling, J. (2022). Signs of learning: Multiple modes as support for interaction in a linguistically diverse physics classroom. Education Sciences, 12(10), 662. https://doi.org/10.3390/educsci12100662

Laras, W., Siswoyo, & Fauzi, B. (2015). *Pendekatan multi representasi. Jurnal Penelitian & Pengembangan Pendidikan Fisika*, 1(1), 31–38.

Li, M. (2020). Multimodal pedagogy in TESOL teacher education: Students' perspectives. *System*, 94, 102337.

Liana, M., Sinaga, P., & Emiliannur, E. (2023). Physics workbook using multimodal representation on simple harmonic motion topic. *Jurnal Penelitian Pendidikan* IPA, 9(9), 7503–7513.

Marshall, D., & Conana, H. (2022). Multimodality and new materialism in science learning: Exploring insights from an introductory physics lesson. *Education as Change, 25*, 1–19. https://doi.org/10.25159/1947-9417/8848

Masrifah, A., Agus, S., Parlindungan, S., & Wawan, S. (2020). An investigation of physics teachers' multiple representation ability on Newton's law concept. Jurnal Penelitian dan Pengembangan Pendidikan Fisika, 6(1).

Mayer, R. E. (2007). Thinking, problem solving, cognition (2nd ed.). Freeman.

Mayer, R. E. (2009). Multimedia learning (2nd ed.). Cambridge University Press.

Merta, S., Parlindungan, S., & Utari, S. (2022). Effect of application of physics learning material using multimode representation to improve problem-solving ability. https://doi.org/10.2991/ICMSED-16.2017.33

Muhammad, I., Zaenati, L., Farida, N., & Than, K. W. (2023). The influence of student attitudes on learning achievement. https://doi.org/10.22437/jiituj.v7i2.26697

Munfaridah, N., Avraamidou, L., & Goedhart, M. (2021). The use of multiple representations in undergraduate physics education: What do we know and where do we go from here? Eurasia *Journal of Mathematics, Science and Technology Education*, 17(1), em1934.

Nickerson, R. S., Perkins, D. N., & Smith, E. E. (2014). The teaching of thinking. Routledge.

Nigerian Educational Research Development Council (NERDC). (2009). Secondary school physics curriculum. NERDC Press.

Ogunleye, A. O., & Baba, T. A. (2011). Effects of computer simulations on secondary school students' attitudes toward physics. *International Journal of Education in Science and Technology*, 13(2), 112–119.

Ogunleye, O. O. (2014). The decline of enthusiasm in science among secondary school pupils. *European Journal of Educational Sciences*, 3(1), 37–40.

O'Halloran, K. L., Tan, S., & E, M. K. (2017). Multimodal analysis for critical thinking. *Learning, Media and Technology*, 42(2), 147–170.

Opfermann, M., Schmeck, A., & Fischer, H. (2017). Multiple representations in physics and science education. Why should we use them? In Multiple representations in physics education (pp. 1–22). Springer. https://doi.org/10.1007/978-3-319-58914-5_1

Orulebaja, Y., Owolabi, T., & Akintoye, H. (2021). Effects of multiple representations and problem-solving learning strategies on physics students' problem-solving abilities. *International Journal for Innovation Education and Research*, 9(4).

Palanisamy, S. (2020). *Effectiveness of Mayer's problem solving model with visual representation teaching strategy in enhancing year four pupils' mathematical solving ability* (Master's thesis, University of Malaya).

Pascasie, N., Minani, E., & Nduwingoma, M. I. K. (2022). A scientometric review of multimedia in teaching and learning of physics. LUMAT, 10(1). https://doi.org/10.31129/lumat.10.1.1634

Philippe, S., Souchet, A. D., Lameras, P., Petridis, P., Caporal, J., Coldeboeuf, G., & Duzan, H. (2020). Multimodal teaching, learning and training in virtual reality: A review and case study. *Virtual Reality & Intelligent Hardware*, 2(5), 421–442.

Pongprapan, P. (2024). Unpacking the factors that influence secondary students' attitudes towards physics in nine different countries—A cross-cultural analysis. Physics Education, 59(5), 055006. https://doi.org/10.1088/1361-6552/ad5f6e

Pozhham, P., Godarzi, K., & Roozbehani, M. (2019). Investigating the relationship between critical thinking and academic achievement among male students. *International Journal of Philosophy and Social Psychological Sciences*, 5(3), 9–17.

Rau, M. A. (2017). Conditions for the effectiveness of multiple visual representations in enhancing STEM learning. *Educational Psychology Review*, 29, 717–761.

Reima, A. J. (2024). Multimodal teaching and learning in the EFL college classroom. Journal of English Language Teaching and Applied Linguistics, 6(4), 68–75. https://doi.org/10.32996/jeltal.2024.6.4.7

Samba, R. M., Achor, E. E., Bash, A. E., & Iortim, S. O. (2020). Fostering students' critical thinking and achievement in basic science using graphic organizer and experiential learning strategies with feedback. *Science Education International*, 31(2), 220–225. https://doi.org/10.33828/sei.v31.i2.12

Suryawati, E., & Osman, K. (2017). Contextual learning: Innovative approach towards the development of students' scientific attitude and natural science performance. *Eurasia Journal of Mathematics, Science and Technology Education*, 14(1), 61–76.

Telima, A. (2019). Why students in secondary schools choose not to do physics? Implications for policy and practice in developing countries. European Scientific Journal, 15(34), 103. https://doi.org/10.19044/ESJ.2019.V15N34P103

Treagust, D., Won, M., & McLure, F. (2018). Multiple representations and students' conceptual change (pp. 121–128). Routledge. https://doi.org/10.4324/97813546739

Tsania, N. D., Sutopo, S., Handayanto, K., & Kusairi, S. (2024). Demographic factors associated with students' belief and attitude towards physics and learning: A cross-sectional study from Indonesia. Participatory Educational Research, 11(6), 75–93. https://doi.org/10.17275/per.24.80.11.6

Vygotsky, L. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.

Wankat, P. C., & Oreovicz, F. S. (2015). *Teaching engineering*. Purdue University Press.

Wenzhong, G., Jianwen, W., & Shiping, W. (2019). Deep multimodal representation learning: A survey. IEEE Access, 7, 63373–63394. https://doi.org/10.1109/ACCESS.2019.2916887

West Africa Examination Council. (2014). Chief examiners' report: General comment, weakness/remedies and candidate's strength. Retrieved June 10, 2019, from https://waeconline.org.ng/e-learning/Biology/Bio223mc.html

West Africa Examination Council. (2016). Chief examiners' report: General comment, weakness/remedies and candidate's strength. Retrieved June 10, 2019, from https://waeconline.org.ng/e-learning/Biology/Bio225mc.html

West African Examinations Council. (2015). *Regulation and syllabus for West African Senior Secondary School Certificate Examination* (WASCE).

Winda, M., Mitri, I., & Maimurni, M. (2019). Applying multirepresentation-based physics learning to improve the ability of representation of students in class X MIPA2 SMAB Abussalam Pekanbaru. Jurnal Guru Sekolah, 6(2), 67–74. https://doi.org/10.31258/JGS.6.2.67-74

Yanxiang, G., Juan, G., & Xiangli, S. (2024). The cultivation of critical thinking ability in middle school physics teaching. Deleted Journal, 7(3), 1–3. https://doi.org/10.54097/nqd48z70

Zheng, B., & Warschauer, M. (2015). The impact of multimedia learning on secondary students' attitudes toward physics. *Journal of Educational Technology Development and Exchange*, 8(2), 79–91.