Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 10, No. 6, 147-159
2026
Publisher: Learning Gate
DOI: 10.55214/2576-8484.v10i6.12982

Effect of multimedia pedagogy on students' achievement in hybridization and molecular shapes in selected secondary schools in volta region

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Abstract: This study examined the effect of multimedia pedagogy on students' academic achievement in hybridization and molecular shapes among selected secondary schools in the Volta Region. The study focused on four cognitive levels of Bloom's Taxonomy: remembering, understanding, applying, and analyzing. A quasi-experimental pretest–posttest control group design was employed, involving 81 SHS 2 chemistry students drawn from two existing classroom cohorts. The experimental group (44 students) received instruction through multimedia pedagogy, while the control group (37 students) was taught using conventional teaching methods over a four-week period. Data were collected using the Hybridization and Molecular Shapes Performance Test and analyzed using descriptive statistics and one-way ANOVA. The findings revealed a significant improvement in the experimental group's academic performance, with mean scores increasing from 45.20 in the pre-test to 72.35 in the post-test. The results further indicated statistically significant differences across cognitive levels, with students demonstrating stronger performance at the application level than at the comprehension and analysis levels. It was recommended that curriculum frameworks should integrate interactive digital resources to complement and enhance traditional teaching methods. Implications includes chemistry teachers should integrate multimedia-based instructional approaches into classroom practice to improve learners' understanding of abstract concepts and enhance overall academic achievement.

Keywords: *Bloom's Taxonomy, Chemistry education, Hybridization, Molecular shapes, Multimedia pedagogy, Secondary education, Students' performance.*

1. Introduction

Over the years, Ghana has been working tirelessly to promote scientific and technological capabilities in response to global trends [1]. In this regard, efforts have been made to improve science education at the senior high school level. This serves to assist students in acquiring higher-order thinking skills to solve problems, apply, analyze, and create [2]. Chemistry is central in this national plan because of its relevance in improving students' knowledge of matter and its transformations. However, studies show that many topics in chemistry, especially hybridization and molecular shapes, are taught in abstract, posing persistent learning difficulties across academic levels [3-5]. This traditional method of teaching concepts such as hybridization made it difficult for students to comprehend. This is because most of the students do not have prerequisite knowledge such as electronic configuration, atomic orbitals, and bonding principles. Many studies have found that students struggle to visualize molecular structures and spatial arrangements, which leads to poor academic performance [6, 7]. This mostly results from teachers' continual use of traditional lecture-based teaching methods [8]. Such teaching methods cause the challenges students face in many classrooms to be reflected in their academic performances [9].

History: Received: 20 March 2026; Revised: 13 May 2026; Accepted: 18 May 2026; Published: 5 June 2026
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Multimedia pedagogy has been identified as a promising instructional approach to address these challenges [10]. Multimedia helps students to visualize complex concepts and promotes deeper conceptual understanding through the integration of text, animations, simulations, videos, and other digital tools [11]. The approach aligns with interactive and learner-centered environments that enhance participation, retention, and higher-order thinking skills. Notwithstanding these advantages, the implementation of multimedia pedagogy in many Ghanaian senior high schools is constrained by reliance on traditional instructional practices [12]. In this regard, this study aims to provide empirical evidence on how multimedia pedagogy affects students' performance in hybridization and molecular shapes within the Ghanaian context. It measures the cognitive levels of Bloom's taxonomy, particularly remembering, understanding, applying and analyzing.

This gap highlights the necessity for further investigation into the efficacy of multimedia-based instruction in enhancing students' conceptual understanding and academic performance in chemistry. The outcome of the study can be used to inform policy and practice. Particularly, it serves as a useful guide to teachers, curriculum developers, and policymakers for the integration of multimedia strategies in chemistry instruction to improve students' learning and overall performance.

2. Literature Review

2.1. Student Academic Performance

Strong student academic performance is essential, as it increases students' chances of securing good job opportunities and plays a crucial role in shaping their future career paths [13]. Students' performance in science education is measured through tests, exams, and practical tasks, which reflect how well they achieve educational goals and apply and analyze scientific concepts [14]. However, when learners struggle to understand abstract concepts in chemistry, such as hybridization, and are unable to visualize atomic and hybrid orbitals, and have difficulty interpreting molecules in three-dimensions negatively affects their academic performances and their future career path [15].

2.2. Hybridization and Molecular Shapes

According to Lieber and Cox [16], hybridization is the mixing of atomic orbitals to form new, equivalent hybrid orbitals that are oriented in space to support chemical bonding and explain molecular geometry. As explained by VSEPR theory, molecular shape is the three-dimensional arrangement of atoms in a molecule determined by the spatial distribution of electron pairs that arrange themselves to minimize repulsion [17]. Hybridization and molecular shapes are highly abstract and pose persistent learning difficulties across academic levels [3-5]. Research shows that students' understanding of hybridization and molecular shape is vital because it encourages deeper understanding and problem-solving in chemistry education [15].

2.3. Multimedia Pedagogy

Multimedia pedagogy has become an important instructional approach in science education due to its ability to improve students' academic performance, particularly in abstract subject areas such as chemistry Kiat et al. [18]. Nurhatmi [19] stated that Multimedia pedagogy is an instructional approach that involves multiple forms of media, such as text, images, audio, video, and animation, that support purposeful learning in schools [19]. As this is grounded in the Cognitive Theory of Multimedia Learning (CTML), learning is enhanced when information is presented through both verbal and visual channels [10]. This enables students to construct meaningful understanding. This method supports meaningful learning and lightens cognitive pressure when dealing with hybridization and molecular shapes.

Research has shown that students' performance in science subjects improved significantly due to multimedia pedagogy [20, 21]. Students see orbital overlaps and molecular geometry, which are complex to understand using traditional teaching methods, with the assistance of animations and simulations [11, 22]. Videos and interactive models further enhance learning by combining auditory and visual elements, improving retention and comprehension [10]. Research also suggests that combining multiple multimedia tools leads to better learning outcomes, as different tools address different cognitive needs [23]. Students' academic performance improves when the multimedia pedagogy instructional approach is employed in teaching and learning of hybridization and molecular shapes, especially when multimedia tools are used appropriately to enhance meaningful learning Zhou [24]. Far'i et al. [25] also noted that Multimedia approaches increase students' motivation and engagement during teaching and learning, which positively influences their learning outcomes.

2.4. Bloom's Taxonomy

Bloom's Taxonomy was developed by Bloom [26]. Its main aim is to classify educational learning objectives into levels of complexity and specificity. This helps teachers design lessons that promote higher-order thinking skills rather than simple memorization. In the early 2000s, it was revised by Anderson and Krathwohl. The purpose of the revision was to update the framework to better reflect modern understanding of learning [27]. This makes it dynamic by changing the categories into active verbs and emphasizing the application and creation of knowledge in addition to understanding it.

The revised form of Bloom's Taxonomy appears as a pyramid structure showing the progression of thinking skills [27]. At the base is Remembering, which involves recalling basic facts and information [28]. Building on this is Understanding, where learners interpret and make sense of what they have learned. The next level, Applying, focuses on using knowledge in familiar or slightly different situations [29]. As learners move upward, analyzing requires them to break information down and explore relationships between ideas. This is followed by evaluating, which involves making informed judgments based on evidence or criteria [30]. At the top is Creating, the most advanced level, where learners use their knowledge to develop new ideas or produce original work [31]. The pyramid shows a clear shift from foundational skills to more complex, higher-order thinking as one moves upward. The details of Bloom's Taxonomy are shown in Figure 1.

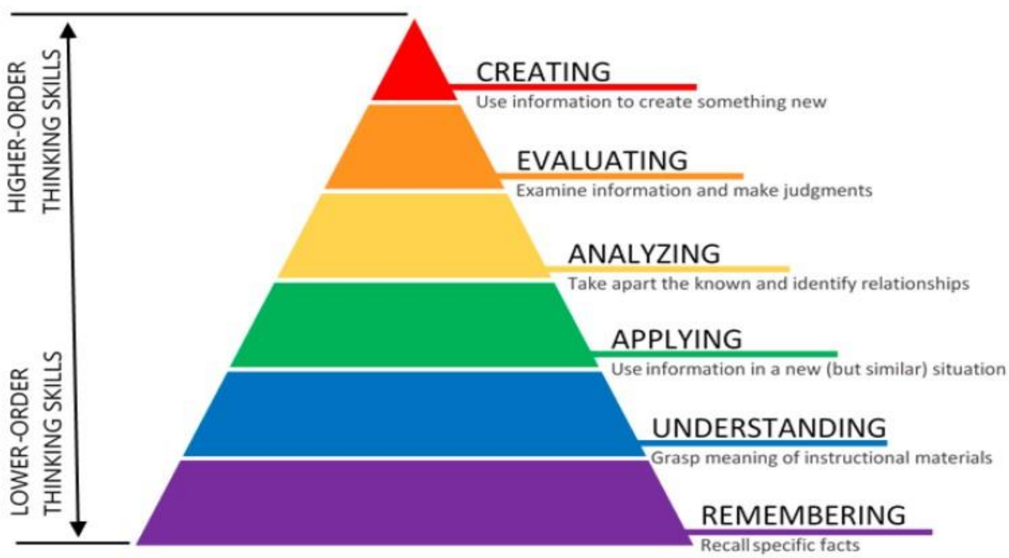

Figure 1.
Bloom's Taxonomy developed.
Source: Anderson and Krathwohl [27].

In this study, how multimedia pedagogy influences learning across different cognitive levels of Bloom's taxonomy is examined. This includes understanding, applying, and analyzing. Bloom's Taxonomy is a hierarchical framework in education to organize learning objectives into levels of

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 10, No. 6: 147-159, 2026
DOI: 10.55214/2576-8484.v10i6.12982

cognitive complexity that assist educators in planning instructional goals moving from remembering information to comprehension, application and analysis [32]. Unlike traditional methods that often emphasise recall, multimedia-based instruction promotes higher-order thinking by engaging students in interactive and problem-solving activities [33]. This makes it particularly suitable for improving performance not only at the basic level of understanding but also at deeper levels of learning. Although previous studies have demonstrated the effectiveness of multimedia pedagogy in improving students' performance in chemistry education, there is limited research examining its effect on hybridization and molecular shapes across different cognitive levels of Bloom's taxonomy within the Ghanaian senior high school context. This gap justifies the need for further investigation.

2.5. Conceptual Framework

Figure 2 presents a clear progression, showing how the use of multimedia supports learners in developing their ability to understand concepts, apply them in meaningful contexts, and engage in deeper analysis. The multimedia pedagogy is considered the independent variable, while students' performance in hybridization and molecular shapes is the dependent variable. The study also investigated academic performance at the cognitive levels of Bloom's taxonomy: understanding, applying, and analyzing. Multimedia pedagogy employs text, animations, simulations, and videos to boost students' understanding of abstract chemistry concepts by helping them visualize and engage more.

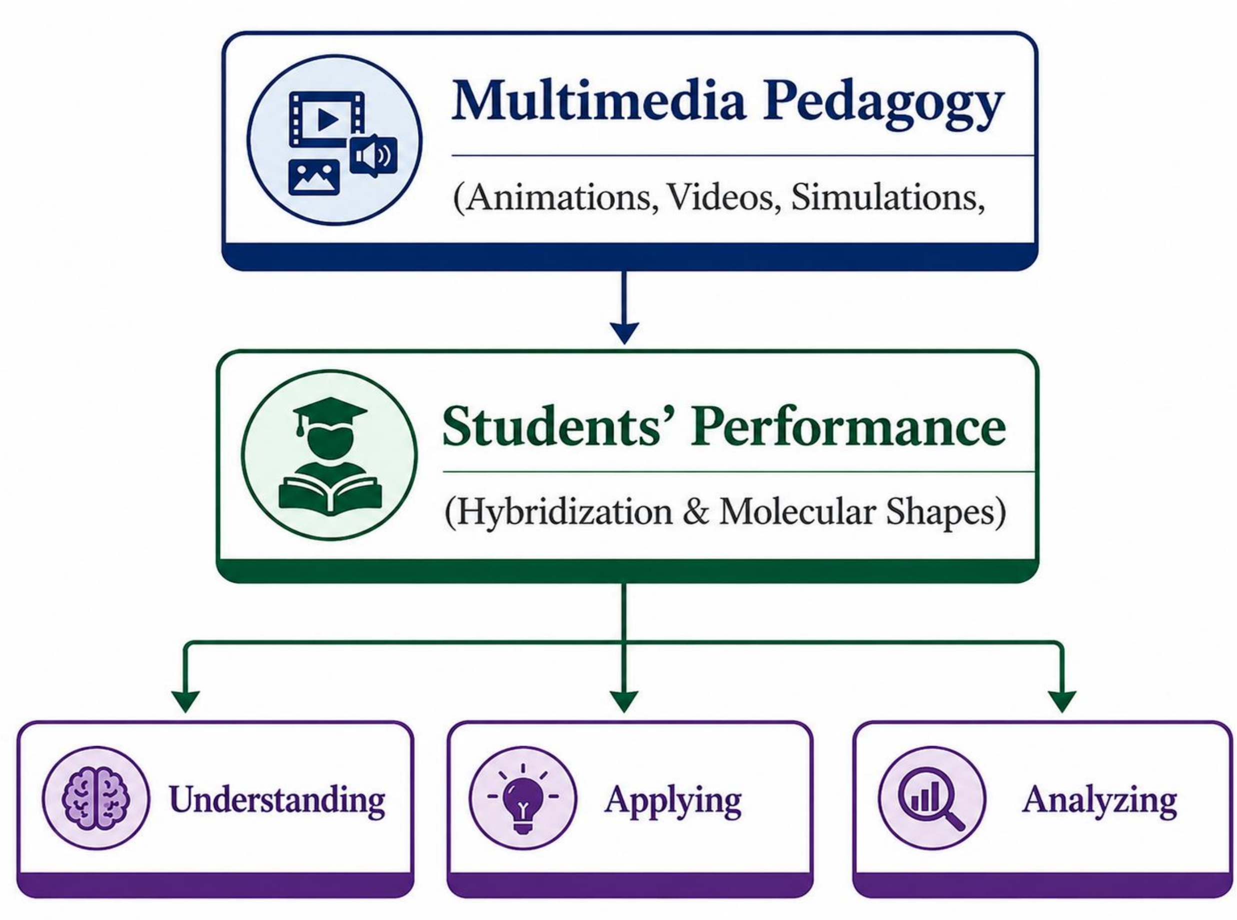

Figure 2.
Interconnected concepts emerged from the theoretical framework.

2.6. Research Question

What is the effect of multimedia pedagogy on students' performance in hybridization and molecular shapes across the cognitive levels of Bloom's taxonomy?

3. Methodology

3.1. Research Design

A quasi-experimental pretest–posttest control group design was utilized to examine the effect of multimedia pedagogy on students' performance in hybridization and molecular shapes. Two intact groups were employed: an experimental group (Anlo SHS), which experienced multimedia instruction, and a control group (Zion College), which received traditional teaching. The two groups took pretests and posttests. The motive of designing test instruments was to examine students' performance at the levels of comprehension, application, and analysis in accordance with Bloom's Taxonomy. This made it easy for the comparison of learning performances across cognitive levels. The design was appropriate because random assignments do not function well in educational institutions. The classes were matched with key characteristics, and pretest scores were used to control for initial differences to enhance group equivalence.

3.2. Population and Sample

The target population for this study comprised all General Science students in the Anloga Municipality, as this group represents the broader category to which the findings are intended to be generalized. From this population, General Science students from Anlo Senior High School and Zion College were identified as the accessible population. A cluster sampling technique was employed, whereby intact classes within selected schools served as natural clusters. This approach was considered appropriate given the structured nature of school settings, where students are already organized into classes, making it both practical and efficient for educational research. Consequently, a total of 81 SHS 2 chemistry students were selected from two intact classes: 44 students from Anlo Senior High School (experimental group) and 37 students from Zion College (control group).

The selection of these schools was guided by several considerations, including comparability in terms of academic structure and curriculum delivery, accessibility to the researcher, availability of qualified chemistry teachers, and their relevance to the study objectives. Using intact classes helped to preserve the natural classroom environment and minimize disruption to regular instructional activities. This also enhanced the ecological validity of the study, as the intervention was implemented within a real teaching and learning context.

3.3. Data Collection Instruments

Research-developed tests were used to collect quantitative data. Hybridization and Molecular Shapes Performance Tests (HMSPT-1 and HMSPT-2) were conducted as pretest and posttest, respectively. The test examined students' performance in hybridization and molecular shapes across the levels of comprehension, application, and analysis based on the cognitive levels of Bloom's Taxonomy. The test consists of multiple-choice and short-answer items highlighting topics like hybridization of atomic orbitals, bonding, and molecular geometry. The instruments were grouped into sections according to the cognitive levels and were administered within 1 hour. Baseline performance was determined using pretest scores, while the effect of the intervention was measured using posttest scores.

3.4. Data Collection and Analysis Procedures

Three phases were used for the data collection: pre-intervention, intervention, and post-intervention. Hybridization and Molecular Shapes Performance Test (HMSPT-1) was administered to the experimental and control groups to determine baseline performances.

The experimental group received instructions using multimedia pedagogy (videos, animations, simulations, and PowerPoint), while conventional methods were used to teach the control group over a period of four weeks. The posttest (HMSPT-2) was implemented to both groups under similar conditions after the intervention. The test scores were recorded and analyzed to compare students' performance before and after the intervention.

3.5. Validity and Reliability

Experts' reviews by experienced chemistry teachers and the researcher's supervisor were used to ensure the validity of the Hybridization and Molecular Shapes Performance Tests (HMSPT-1 and HMSPT-2). Their responses led to changes to enhance the relevance, clarity, and alignment of the test items with the objectives of the study. A pilot group of 20 students was used to establish the reliability of the instruments. 0.79 for HMSPT-1 and 0.83 for HMSPT-2 of reliability coefficients were obtained, revealing that they were acceptable to high levels of consistency.

4. Results

Table 1 shows the demographic characteristics of the participants who took part in the study. It shows how the respondents are spread out based on gender and age across experimental and control groups.

Table 1.
Demographic Characteristics of Participants (N = 81).

Variable	Category	Experimental Group (%)	Control Group (%)	Total (%)
Gender	Male	20 (45.45)	19 (51.35)	39 (48.15)
	Female	24 (54.55)	18 (48.65)	42 (51.85)
Age (years)	14	2 (4.55)	1 (2.70)	3 (3.70)
	15	8 (18.18)	4 (10.81)	12 (14.81)
	16	11 (25.00)	13 (35.14)	24 (29.63)
	17	17 (38.64)	11 (29.72)	28 (34.57)
	18	2 (4.55)	6 (16.22)	8 (9.88)
	19	4 (9.09)	2 (5.41)	6 (7.41)

Table 1 shows the participants' demographic characteristics in terms of gender and age. The results present 39 males (48.15%) and 42 females (51.85%). In the experimental group, females (54.55%) slightly outnumbered males (45.45%), whereas in the control group, males (51.35%) were slightly more than females (48.65%). Most participants were between 16 and 17 years, accounting for 29.63% and 34.57% respectively. Students with 14 (3.70%) and 19 (7.41%) had small proportion. Most participants fall within the typical senior high school age range, indicating that the sample is representative of the target population.

Table 2.
Pre-test and post-test performance results.

Group	N	Pre-Test Mean ± SD	Post-Test Mean ± SD	Mean Difference	t-value	df	p-value	Interpretation
Experimental Group	44	45.20 ± 6.10	72.35 ± 5.80	27.15	18.42	43	<0.001	Significant improvement
Control Group	37	44.80 ± 5.90	49.10 ± 6.20	4.30	1.85	36	0.072	Not significant

Table 2 presents results from the Hybridization and Molecular Shapes Performance Test (HMSPT-1) indicating differences in learning outcomes between the two groups. The experimental group ($n = 44$) recorded a strong improvement from the pre-test ($M = 45.20$, $SD = 6.10$) to the post-test ($M = 72.35$, $SD = 5.80$), with a mean gain of 27.15. This improvement was statistically significant ($t = 18.42$, $df = 43$, $p < 0.001$), indicating that the intervention had a meaningful and positive impact on students' understanding. However, the control group ($n = 37$) showed only a modest increase from the pre-test

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 10, No. 6: 147-159, 2026
DOI: 10.55214/2576-8484.v10i6.12982

(M = 44.80, SD = 5.90) to the post-test (M = 49.10, SD = 6.20), with a mean difference of 4.30, which was not statistically significant (t = 1.85, df = 36, p = 0.072). This suggests that traditional instruction alone did not result in substantial improvement. Therefore, it can be said that the intervention was more effective in strengthening students' conceptual understanding of hybridization and molecular shapes compared to conventional teaching methods.

4.1. Comparative Analysis of Participants' Performance Across Cognitive Domains

Figure 3 indicates that participants performed at relatively similar levels across the three cognitive domains, with Applying (32%) recording the highest mean score, followed closely by Understanding (31%) and Analyzing (30%). The overlap in the 95% confidence intervals suggests that the differences among the three domains are minimal and may not represent substantial variation in performance. This trend shows that learners were able to understand the concepts taught and apply them effectively in learning tasks. However, the slightly lower score in Analyzing may be attributed to the greater cognitive demands required at this level, as analytical tasks often involve deeper reasoning and critical evaluation. From an educational perspective, these findings suggest that the instructional strategies employed, particularly the use of multimedia pedagogy, were effective in promoting balanced achievement across the cognitive levels. Nevertheless, there is a need to further strengthen learners' higher-order thinking skills by incorporating more activities that promote analysis, such as problem-solving tasks, guided inquiry, and critical reflection exercises. Enhancing these aspects of instruction can support learners in progressing from basic understanding and application to more advanced analytical thinking and independent knowledge construction.

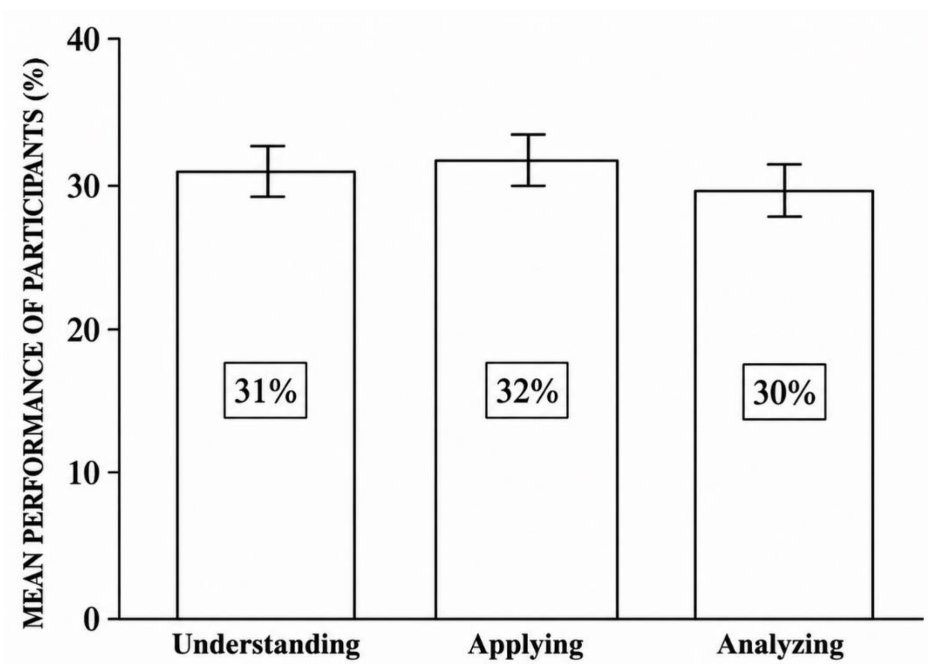

Figure 3.
Cognitive levels of participants (Error Bars 95% Cl).

Table 3 summarises the results of the tests used to check whether the data meet the assumptions of normality and homogeneity of variances. While the Kolmogorov-Smirnov test is significant (p = 0.002), indicating some deviation from normality, the Shapiro–Wilk test (p = 0.051) is slightly above the .05 threshold. This suggests that the data can still be treated as approximately normally distributed. As the Shapiro-Wilk test is generally considered more appropriate for this sample size, the assumption of normality can reasonably be accepted. Furthermore, Levene's test is not significant ($p = 0.127$), indicating that the variances are equal across groups. This provides confidence in the validity of subsequent comparisons across cognitive domains. This is because it can be learnt from the results that any differences observed in performance are unlikely to be affected by violations of statistical assumptions.

Table 3.
Tests of Normality/ Homogeneity of Variances.

Kolmogorov-Smirnov[a]			Shapiro-Wilk			Levene's test			
Statistic	**df**	**Sig.**	**Statistic**	**Df**	**Sig.**	**Statistic**	**df1**	**df2**	**sig**
0.100	132	0.002	0.980	132	0.051	2.100	2	129	0.127

4.2. Lilliefors Significance Correction

Table 3 shows results of a one-way analysis of variance (ANOVA) examining whether there were statistically significant differences in students' academic performance in hybridization and molecular shapes across the three cognitive levels of Bloom's taxonomy. The independent variable, cognitive level, comprised three groups: Understanding ($M = 31.05$, $SD = 2.28$), Applying ($M = 32.41$, $SD = 3.03$), and Analyzing ($M = 29.77$, $SD = 2.69$), with a total sample size of $N = 44$. The assumption of normality was assessed using the Shapiro–Wilk test (see Table 4) and was found to be tenable ($p = .051$). Similarly, the assumption of homogeneity of variances was met, as indicated by Levene's test, $F(2, 129) = 2.10$, $p = 0.127$.

The ANOVA results revealed a statistically significant difference in academic performance across the three cognitive levels, $F(2, 129) = 10.61$, $p < 0.001$. Furthermore, the effect size, as measured by partial eta squared ($\eta^2 = .141$), indicates a large effect, suggesting that approximately 14.1% of the variance in students' performance can be attributed to differences in cognitive level. These results provide strong evidence that students' performance varies significantly across the cognitive domains, likely influenced by the differing cognitive demands associated with each level and the use of multimedia pedagogy in instruction.

Table 4.
Analysis of variance (one-way ANOVA) of students' academic performance at the three cognitive levels of Bloom's taxonomy.

Source	SS	df	MS	F	p	η^2
Between groups	152.97	2	76.49	10.61	0.000	.141
Within groups	930.27	129	7.21			
Total	1083.24	131				

The results of the Tukey HSD post hoc analysis presented in Table 5 show where the differences in students' academic performance occur across the three cognitive levels. A statistically significant difference was found between Understanding and Applying ($p = 0.049$), with students performing better at the Applying level. Likewise, a highly significant difference was observed between Applying and Analyzing ($p < 0.001$), again indicating stronger performance in Applying compared to Analyzing. On the other hand, the difference between Understanding and Analyzing was not statistically significant ($p = 0.071$). This suggests that performance at these two levels is relatively similar. The results indicate that students perform best when applying knowledge, while analyzing appears to be more demanding. This suggests that instructional approaches, including multimedia pedagogy, are effective in supporting Understanding and Application. Therefore, there remains a need to further strengthen teaching strategies that specifically target higher-order thinking skills, particularly Analytical ability.

ISSN: 2576-8484
Vol. 10, No. 6: 147-159, 2026
DOI: 10.55214/2576-8484.v10i6.12982

Table 5.
Multiple comparisons, post hoc Tukey HSD analysis of students' academic performance at the three cognitive levels of Bloom's taxonomy.

(I) Cognitive Levels of Participants	(J) Cognitive Levels of Participants	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Understanding	Applying	-1.364*	0.573	0.049	-2.72	-0.01
	Analyzing	1.273	0.573	0.071	-0.08	2.63
Applying	Understanding	1.364*	0.573	0.049	0.01	2.72
	Analyzing	2.636*	0.573	0.000	1.28	3.99
Analyzing	Understanding	-1.273	0.573	0.071	-2.63	0.08
	Applying	-2.636*	0.573	0.000	-3.99	-1.28

Note: *The mean difference is significant at the 0.05 level.

5. Discussions

This study examined the impact of multimedia pedagogy on students' performance in hybridization and molecular shapes, with a focus on cognitive levels, including understanding, applying, and analyzing, at senior high school. The data analysis was anchored around three central or core research questions and their corresponding null hypotheses, all evaluated at the 0.05 level of significance. The core objective was to determine whether multimedia pedagogy or multimedia-based instruction significantly enhances students' conceptual understanding and cognitive engagement in the teaching of hybridization and molecular shapes, a topic often cited in the literature as abstract and difficult for students or learners.

The findings of this study indicate that multimedia pedagogy can play a meaningful role in enhancing learning across the different cognitive levels outlined in Bloom's taxonomy, including foundational skills such as understanding, applying and analyzing. This stands in contrast to Almasseri and AlHojailan [34], who found no significant differences at these lower levels. A possible explanation for this difference lies in the type of multimedia used. Their approach relied largely on passive tools, such as online videos supported by e-books, text files, and images, which may not have encouraged sufficient learner engagement to produce measurable improvements. However, the current study appears to reflect the use of more interactive and cognitively engaging multimedia strategies. For instance, at the "remember" level, multimedia flashcard applications that combine visual and audio elements can strengthen recall [35], while at the "understand" level, explainer videos paired with guided questions can support learners in interpreting and summarising information more effectively [36]. This implies that the effectiveness of multimedia pedagogy depends on how it is applied and the extent to which it actively involves learners in the learning process.

Furthermore, the moderately strong effect identified through the one-way ANOVA ($F(2,129) = 10.61$, $p < 0.001$) is consistent with the findings of Sun et al. [37] and Teng et al. [38], both of whom emphasise the benefits of thoughtfully designed multimedia aligned with cognitive frameworks such as the revised Bloom's taxonomy. These studies highlight that the impact of technology in education depends not only on its presence but on how effectively it is used to support different levels of thinking. For example, Teng et al. [38] describe the use of scenario-based videos in moral education, where students engage with ethical dilemmas, consider possible responses, and justify their decisions, thereby developing higher-order thinking skills such as analysis and evaluation. Similarly, Sun et al. [37] report that tools like interactive storytelling and gamified learning environments can enhance both cognitive outcomes, such as the ability to apply knowledge in new contexts, and affective outcomes, including motivation and engagement. These approaches reinforce knowledge and promote deeper understanding and meaningful learner involvement.

The post hoc results show a clear variation in how learners performed across cognitive levels, with the strongest outcomes at the application level ($M = 32.41$, $SD = 3.03$), followed by comprehension ($M = 31.05$, $SD = 2.28$), and the lowest scores at the analysis level ($M = 29.77$, $SD = 2.69$). Rather than being a random pattern, this distribution reflects how different cognitive demands interact with the strengths of multimedia-based instruction. Richter and Scheiter [39] found that multimedia pedagogy does not influence all types of thinking in the same way. In this case, the higher performance in application suggests that learners benefited most when they were required to use knowledge in practical or contextual situations. Multimedia environments are particularly effective here because they present information in dynamic and concrete forms, which help learners bridge the gap between theory and practice. This aligns closely with Mayer [10] cognitive theory of multimedia learning, which argues that meaningful learning occurs when learners process information through both visual and verbal channels in a coherent and structured manner. This suggests that multimedia resources help learners form stronger mental models by making abstract concepts visible and easier to follow. In a similar vein, Moreno and Mayer [40] emphasise that interactivity encourages active engagement with content, allowing learners to manipulate information and construct understanding more effectively than through passive exposure alone. This interactive element is particularly beneficial for application-based tasks, where learners must demonstrate practical understanding rather than simple recall.

From a curriculum perspective, Bloom's revised taxonomy [27] provides further clarity. Application sits at a mid-level of cognitive complexity, requiring learners to use what they know in meaningful ways without necessarily engaging in deep structural breakdown or evaluation. Multimedia instruction tends to support this level well because it often includes demonstrations, guided examples, and immediate feedback. In contrast, analysis requires more advanced cognitive effort, including identifying relationships, interpreting patterns, and drawing inferences, which are inherently more demanding.

The lower performance observed at the analysis level can be better understood through cognitive load theory [41]. Analytical tasks place greater demands on working memory because learners must process multiple elements simultaneously, establish connections between ideas, and engage in higher-order reasoning. Even when multimedia resources are well designed, these demands can still be challenging if sufficient scaffolding is not provided. Despite this variation, the overall findings still provide strong support for the effectiveness of multimedia pedagogy. This aligns with Clark and Mayer [42] that when multimedia instruction follows key design principles such as modality (balancing visual & verbal input), contiguity (aligning related information), and coherence (removing unnecessary content) it enhances both understanding and deeper learning. The relatively strong performance at comprehension and application levels in this study suggests that these principles were likely applied effectively, enabling learners to build understanding and successfully transfer it into practice.

6. Recommendations

i. The Ministry of Education should prioritise investment in strong digital infrastructure, including reliable internet access, smart classroom technologies, and learning management systems. This can ensure that all schools can implement multimedia-based learning fairly and effectively.
ii. Curriculum frameworks should also evolve beyond traditional lecture-based teaching and formally integrate interactive digital resources as recognized instructional materials.
iii. Teachers need sustained professional support to develop effective scaffolding strategies that guide learners from basic understanding towards higher-order thinking skills, particularly in challenging areas such as analytical reasoning.
iv. Future researchers should value exploring how factors such as learners' prior knowledge, digital literacy, and individual learning preferences influence the effectiveness of multimedia-based instruction.

7. Conclusion

This study investigates the impact of multimedia pedagogy on senior high school students' understanding of hybridization and molecular shapes. It focuses on cognitive performance guided by the cognitive level of Bloom's taxonomy, which includes remembering, understanding, applying, and analyzing. The results indicate a statistically significant effect of multimedia-based instruction on students' cognitive achievement, highlighting the important role that well-designed multimedia resources play in shaping how learners engage with and interpret abstract chemistry concepts. In particular, the results show that multimedia environments are most effective in strengthening conceptual understanding and supporting the application of knowledge in meaningful contexts, as reflected in the highest performance observed at the application level.

The results further reveal that while comprehension was positively influenced, performance at the analysis level was comparatively lower. This suggests that higher-order cognitive skills such as interpretation and inference remain more challenging, even within enriched multimedia learning environments. Although multimedia pedagogy effectively supports foundational and intermediate levels of cognition, learners may still require more structured guidance to fully develop advanced analytical abilities. In this regard, incorporating guided questions and structured reasoning tasks within multimedia lessons is essential. It can promote deeper conceptual engagement and gradually support the development of stronger analytical and inferential thinking skills.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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