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Enriching Students' Cognitive Engagement and Higher-Order Thinking Skills (HOTS) in Endothermic and Exothermic Reactions Using Smart Pedagogy

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Abstract. Smart pedagogy involves using innovative, technology-supported teaching strategies to create adaptable, personalized, and efficient learning experiences. The study investigated whether smart pedagogy, such as blended reality (BR) and virtual reality (VR) learning approaches, could enrich students' cognitive engagement and higher-order thinking skills (HOTS) in the context of endothermic and exothermic reactions. A quasi-experimental non-randomized pre-test, post-test control group research design was adopted in this study. The instrument used for data collection are Endothermic and Exothermic Cognitive engagement Scale (EECES) and Endothermic and Exothermic Higher-Order Thinking Skills Test (EEHOTST) are the instruments used for data collection. RES and RHOTST were validated and trial-tested, which yielded reliability values of 0.87 and 0.92 using Cronbach's Alpha and Kuder-Richardson (KR-21) formula, respectively. 5543 SS2 students offering chemistry in senior secondary schools in Dekina LGA Kogi State, Nigeria was the population of the study. Multi-stage sampling techniques were used to select 156 SS2 students drawn from 6 schools in Dekina LGA. Four research questions and four null hypotheses guided the study. The research questions were answered using Mean and Standard Deviation scores, while the null hypotheses were tested using Analysis of Covariance. It was established among others that there was a significant difference in the mean cognitive engagement ratings and HOTS scores of students taught endothermic and exothermic reactions using the BR learning approach, VR learning approach, and conventional discussion method [$F_{2,\ 155}$=1505.004, P<0.05] [$F_{2,\ 155}$=139.001, P<0.05] respectively It was recommended that chemistry teachers should be encouraged to use smart pedagogy, such as blended reality (BR) and virtual reality (VR) learning approaches, to enrich students' cognitive engagement and HOTS level in endothermic and exothermic reactions.

Keywords: Smart Pedagogy, Students' Cognitive engagement, Higher-Order Thinking Skills (HOTS) Level, Endothermic and Exothermic Reactions

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1 Introduction

Chemistry drives national development by enhancing human capital and increasing national productivity, especially in agriculture, health, manufacturing, and energy sectors. Endothermic and exothermic reactions, which are the main focus of this study, endothermic reactions give energy in or involve the absorption of energy from their surroundings, typically as heat, causing the surroundings to become colder, not warmer. Examples of endothermic processes include photosynthesis, evaporation, melting ice, and the dissolution of ammonium chloride in water, where heat is taken in from the environment. his absorption of energy can lead to a decrease in the temperature of the system, resulting in a cooling effect in the surrounding environment. Conversely, exothermic reactions give energy out or it involve the release of energy (usually as heat) into their surroundings, making the surroundings hotter. This occurs because the new chemical bonds formed in the products are stronger than the bonds that were broken in the reactants, resulting in a net release of energy from the system to the environment. Common examples of exothermic reactions are combustion, the rusting of iron, respiration, and neutralization reactions. These examples illustrate a range of exothermic processes, from rapid and energetic reactions like burning to slower, more sustained processes like rusting and the metabolic energy release within living organisms. Essential processes such as cellular respiration and photosynthesis rely on endothermic and exothermic reactions to provide energy and sustain life. In other words, endothermic and exothermic reactions can be observed in everyday processes. Endothermic reactions are crucial for cooling applications, and exothermic reactions are vital for energy production through combustion and fuel our bodies with cellular respiration, demonstrating their essential roles in powering industry and daily life. Endothermic reactions, which absorb heat, are utilized for cooling in applications like instant ice packs, while exothermic reactions, which release heat, are essential for energy production via combustion and powering life processes such as cellular respiration, thereby underpinning much of our industrial and daily activities. Despite the importance of endothermic and exothermic to our industrial and daily activities, WAEC Chief Examiners' report (2023/2024) highlight consistent students' weakness in endothermic and exothermic in internal and external examinations, attributing it to the difficulty in identifying and distinguishing reactions, misinterpreting temperature changes, incorrectly relating bond breaking and failure to understand energy transfer in term of system and surrounding.

The importance of endothermic and exothermic reactions to daily life cannot be overemphasized. Thus, effective classroom teaching of endothermic and exothermic reactions should be given more serious attention. Students' cognitive engagement during classroom instructions has been reported to be very poor in Nigeria (Ahmed, 2022). Cognitive engagement refers to students' investment and interest in their learning, motivation to learn, goal setting, perception of relevance of learning, effort directed toward learning, and use of self-regulated learning approaches (Pohl, 2020). Students' cognitive engagement is the active investment of effort in thinking, learning, and problem-solving, characterized by a deep interest in a task, the use of self-regulated learning, and the desire to comprehend complex ideas (Rotgans & Schmidt, 2011). In educational contexts, it's a crucial indicator of learning gains, where students who are more cognitively engaged are more likely to achieve higher-order

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thinking skills and overall academic success. Ahmed (2022) opines that students' low cognitive engagement may lead to negative attitudes and poor willingness to put in the necessary effort toward learning, while high cognitive engagement may lead to enriched learning outcomes, improved focus, deeper understanding, and enriched higher-order thinking skills (HOTS). Students often show low cognitive engagement in chemistry due to ineffective teaching methods, leading to avoidance of classroom participation (Ajewole, 2023). Students with low cognitive engagement can create a negative self-fulfilling prophecy, where students don't put forth their best higher-order thinking skills to solve problems. The importance of students' cognitive engagement and its impact on their higher-order thinking skills (HOTS) should be given more serious attention. Thus, teaching approaches that require learners to construct meaning and actively participate, rather than just passively receive information, are crucial to enrich students' cognitive engagement and HOTS.

Students' cognitive engagement level may enrich or weaken their higher-order thinking skills (HOTS) level. This is because students who possess higher cognitive engagement are likely to have higher HOTS due to their participation, invested time, and effort directed toward learning. HOTS is associated with Bloom's taxonomy. In Bloom's taxonomy, HOTS stands for Higher-Order Thinking Skills, representing the top three levels of cognitive processes. It helps group questions into higher-order thinking skills (HOTS) categories such as analysis, synthesis (creation), and evaluation. HOTS requires deeper cognitive processing, critical thinking, and the ability to apply knowledge to novel situations and solve complex problems. HOTS involves critical thinking, reflective thinking, meta-cognition, and creative thinking (Bowker & Fazioli, 2016). HOTS is the capacity to use skills, knowledge, and values in reflection, reasoning, decision-making, problem-solving, and promoting innovation and creativity (Sulaiman, Muniyan, Madhvan, Hasan & Rahim, 2017). HOTS is the ability to use information, skills, and values in decision-making, problem-solving, deep thinking, and innovation (Kwasi & Achor, 2025). HOTS is essential for problem-solving (identify and resolve complex problems effectively). Students' low or weak HOTS abilities can manifest as a reliance on rote memorization, difficulty analyzing information, and a struggle with problem-solving and independent thought.

Kwasi and Achor (2025) lamented that poor students' higher-order thinking skills (HOTS) levels have often been blamed on ineffective teaching methods. Considering, HOTS are crucial for students as they foster critical thinking, creativity, and problem solving, moving beyond rote memorization to enable deeper learning, adaptability, and success in academic, future careers, and real-world challenges. There is a need for a learning paradigm to shift from low-level thinking skills to learning higher-order thinking skills such as analysis, synthesis (creation), and evaluation. Thus, preparing the students to become successful individuals, teachers need to ensure that their teaching is effective. Consequently, considering the fast speed of change and innovation in knowledge, the use or integration of smart technology during teaching and learning processes seems necessary. The integration of smart technology in teaching and learning (smart pedagogy) is the strategic use of digital tools and devices to enhance the educational experience, moving beyond a static, textbook-driven model to an interactive and adaptable one. Smart pedagogy is an emerging and rapidly growing areas that have the potential to transform existing teaching strategies, learning environments, and educational activities.

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Smart pedagogy offers a modern, efficient pathway to enrich classroom active participation and teaching efficiency by focusing on structured lesson planning, active/inclusive classroom, and continuous technology integration (Ajayi, Ameh, Penda, 2025). Smart pedagogy is a set of innovative teaching approaches, methods, and practices to provide smart features. That is, smart pedagogy involves using innovative, technology-enhanced strategies and methods to create an adaptive, self-learning, and optimized educational environment, characterized by 'smart features' such as adaptation, sensing, inferring, anticipation, self-learning, and self-optimization for education processes, objects, and environment. Smart pedagogy refers to teaching methods that leverage rapid, technology-enhanced, and research-backed strategies to create a dynamic classroom environment. This assertion calls for the need to find smart pedagogy, such as blended reality (BR) and virtual reality (VR) learning approaches that may have the potential to enrich students' cognitive engagement and higher-order thinking skills (HOTS) level

Blended reality (BR) learning approach integrates the physical and digital world to create an interactive, seamless learning experience. That is, BR involves adding digital information or objects to your real-world perception. Blended reality learning approach is a learning environment that fosters both face-to-face instruction and digital methods of instruction (Mortera-Gutierrez, 2016). In blended reality, in-person learning is "blended" with technology-based instruction to best meet the diverse needs of students. Students can engage in digital instruction through instructional videos, content on learning management systems, and the use of technology-based cognitive engagement platforms and tools (Acree, 2017). Blended reality enables the teacher to combine online learning content with traditional teacher-facilitated instructional strategies, thus offering students more learning prospects (Fazal and Bryant, 2019). Blended learning has been shown to positively correlate with students' attitudes toward the learning process (Lozano, 2020).

Virtual reality (VR) learning approach fully immerses the learner in a completely digital, simulated environment, blocking out the real world. That is, VR transports you entirely to a digital world. VR learning has been used to bridge the gap between theoretical knowledge and real-world application by simulating authentic scenarios in a controlled setting (Sherman & Craig, 2018). Virtual reality (VR) is an interactive computer-simulated environment that detects a participant's actions and adjusts feedback to create an immersive experience (Sherman & Craig, 2018). In this study, the VR approach involves the integration of virtual reality learning experiences into classroom instruction. It is an interactive teaching/learning approach in which learners can directly interact with virtual objects, test their ideas, and observe their results in real time. The use of the VR approach allows the possibility of representing abstract concepts and virtually manipulating them, providing a suitable platform for understanding chemistry concepts and their relation to the physical world. The VR approach provides students with intimate insights into environments that are typically inaccessible, while keeping them engaged in the learning process. For example, in this study, a chemistry teacher used a VR approach to teach students about endothermic and exothermic reactions by providing an immersive, interactive, and safe virtual laboratory environment where students can visualize molecular energy changes in 3D and manipulate reaction conditions without risk.

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Ryan and Deci's (2000) Self-Determination Theory (SDT) and Bloom's (1956) Taxonomy are effective educational frameworks that anchor this research, with SDT fostering cognitive engagement by satisfying needs for autonomy, competence, and relatedness, while Bloom's Taxonomy provides a structured way to design curricula and assessments that promote higher-order thinking skills (HOTs) and cognitive engagement, moving students beyond rote memorization to critical analysis and creative work. In other words, Bloom's Taxonomy provides a framework for structuring learning objectives and promoting deeper cognitive processes like analysis and creation. Both theories, when applied within a smart pedagogy context, create more balanced, interactive, and effective learning environments that lead to deeper student understanding and growth. Thus, these constructivist principles emphasize active learning and knowledge construction through experience, naturally align with the goals of SDT and the upper levels of Bloom's Taxonomy, creating a robust approach to effective teaching.

Gender inequality has remained a perennial problem of global scope. It has to do with socially constructed differences, which lead to forms of inequality such that the male is regarded as superior and all-knowing and the female as inferior and incompetent (Ajayi, 2025). Some studies indicate that boys achieve better (Penda, 2024), either no difference (Ajayi & Audu, 2023; Ameh, Sor & Ajayi, 2025) or girls outperform boys (Ahmed, 2022) have been demonstrated. Studies on gender differences continued to yield inconsistent results, and it has usually been attributed to unequal exposure of males and females to learning instructions relevant to chemistry learning. A study by Jibril, Issa, Onojah, Aderele, and Onojah (2022). concluded that blended learning enhanced students' academic performance in the educational technology concept than the conventional method. Likewise, Olatunde-Aiyedun and Adams (2022) concluded that learners' achievement and retention in science are significantly improved by blended reality. Danmal, Onansanya, Atanda, and Abdullahi (2024) suggested that virtual reality (VR) technology effectively enhances STEM education for at-risk students at the secondary school level when compared with the traditional method of teaching. Thus, the scarcity of studies on enriching both male and female students' cognitive engagement and higher-order thinking skills in the context of endothermic and exothermic reactions using smart pedagogy necessitated this study.

1.1 Purpose of the Study

The purpose of the study was to find out if smart pedagogy, such as blended reality (BR) and virtual reality (VR), could enrich students' cognitive engagement and higher-order thinking skills level in the context of endothermic and exothermic reactions. Specifically, the study was set out to:

1. Determine the effects of the blended reality (BR) approach, virtual reality (VR) approach, and discussion method on students' cognitive engagement in endothermic and exothermic reactions.
2. Ascertain the interaction effect of treatments and gender on students' cognitive engagement in endothermic and exothermic reactions.
3. Find out the effects of the BR approach, VR approach, and discussion method on students' higher-order thinking skills in endothermic and exothermic reactions.

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4. Ascertain the interaction effect of treatments and gender on students' higher-order thinking skills level in endothermic and exothermic reactions.

1.2 Research Question

The following research questions guided this study:

1. What is the mean cognitive engagement ratings difference among students taught endothermic and exothermic reactions using the blended reality (BR) approach, virtual reality (VR) approach, and discussion method?
2. What is the interaction effect of treatments and gender on students' cognitive engagement rating in endothermic and exothermic reactions?
3. What is the mean difference in higher-order thinking skills scores among students taught endothermic and exothermic reactions using the BR approach, VR approach, and discussion method?
4. What is the interaction effect of treatments and gender on students' higher-order thinking skills scores in endothermic and exothermic reactions?

1.3 Hypotheses

The following null hypotheses guided the study:

1. There is no significant difference in the cognitive engagement ratings of students taught endothermic and exothermic reactions using the BR approach, VR approach, and discussion method.
2. There is no significant interaction effect of treatments and gender on the cognitive engagement ratings of students in endothermic and exothermic reactions.
3. There is no significant difference in the higher-order thinking skills scores of students taught endothermic and exothermic reactions using the BR approach, VR approach, and discussion method.
4. There is no significant interaction effect of treatments and gender on the higher-order thinking skills scores of students in endothermic and exothermic reactions.

2 Method

The research design adopted in this study is quasi-experimental. The study area is Dekina LGA, Kogi State, Nigeria. Dekina LGA of Kogi State is located in the middle belt area of Kogi State, on the A233 highway. Dekina LGA is between latitudes 7^0 41'41" N and longitudes 7^0 01'20" E with a total land mass area of 2461 Km^2 (950 Sq. ml) and has an estimated population of 260 312 (NPC, 2006). 5543 Senior Secondary 2 students in the 39 government-approved Senior Secondary Schools in Dekina LGA is the population of this study. A sample of 156 Senior Secondary 2 students was purposively sampled from 6 schools out of the 39 Senior Secondary Schools in Dekina LGA. The Endothermic and Exothermic Cognitive Engagement Scale (EECES) and the Endothermic and Exothermic Higher-Order Thinking Skills Test (EEHOTST) are the instruments used for data collection.

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The Endothermic and Exothermic Cognitive Engagement Scale (EECES) was a researcher-made 25-item questionnaire that was intended to help students express their level of classroom cognitive engagement in learning and solving problems related to endothermic and exothermic reactions. RES is a 4-point Likert modified rating scale with 4 response options. The options are Very High Extent (VHE), High Extent (HE), Low Extent (LE), and Very Low Extent (VLE). RES is a 4-point Likert scale with number indicators as 4 (VHE), 3 (HE), 2 (LE), and 1 (VLE). Beyond mere understanding of the endothermic and exothermic reaction experiment. The Endothermic and Exothermic Higher-Order Thinking Skills Test (EEHOTST) was 40 multiple-choice tests designed to assess students' higher-order thinking skills (apply, analyze, evaluate, and create). The higher-order thinking skills questions were drawn from WAEC and NECO past questions on endothermic and exothermic reactions.

The instructional lesson plans, Endothermic and Exothermic Cognitive Engagement Scale (EECES), and Endothermic and Exothermic Higher-Order Thinking Skills Test (EEHOTST) were face validated by presenting them to three experts in Chemistry Education/Measurement and Evaluation. Upon validation, the reliability of the instruments was established by administering RES and RHOTST to a randomly selected 34 SS2 students of a senior secondary school, which is not part of the schools used for the main study. After 1 week of 3 periods of teaching, the RES and RHOTST were administered. Cronbach's Alpha was used to ascertain the reliability index of RES, which gave a reliability value of 0.87. The internal consistency of RHOTST, which yielded a reliability value of 0.92, was tested using the Kuder-Richardson (KR-21) formula. During the main study, six chemistry teachers were trained by the researcher using a blended reality (BR) lesson plan and virtual reality (VR) learning plan and discussion lesson plans, respectively, and this lasted for 1 week. After the training, two intact classes were assigned randomly to experimental group 1 (BR approach group), experimental group 2 (VR approach group), and the Control group (Discussion group).

Before actual teaching commences, the Endothermic and Exothermic Cognitive Engagement Scale (EECES) and Endothermic and Exothermic Higher-Order Thinking Skills Test (EEHOTST) were administered as a pre-test by the chemistry teachers, and this lasted for one week. During lessons, the teachers taught the experimental group 1 endothermic and exothermic reactions using the BR approach lesson plan, the teachers taught the experimental group 2 endothermic and exothermic reactions using the VR approach lesson plan, while the control group was taught the same experimental group 2 endothermic and exothermic reactions topics using a discussion lesson plan. This lasted for three weeks. At the end of these actual teaching periods, the pre-test was reshuffled and administered as a post-test, which lasted for one week. The research questions were answered using Mean and Standard Deviation scores, while the null hypotheses were tested using Analysis of Covariance.

3 Results

3.1 Research Question 1

What is the mean cognitive engagement ratings difference among students taught endothermic and exothermic reactions using the blended reality (BR) approach, virtu-

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al reality (VR) approach, and discussion method? Table 1 and Figure 1 presented the answer to research question one

Table 1. Mean Cognitive Engagement and Standard Deviation Scores of Students Taught Endothermic and Exothermic Reactions using the BR approach, VR approach, and Discussion Method

Group	N	PRE- EEES		POST- EEES		Mean Gain within Group
		~		~		
BR approach	51	1.13	0.18	3.79	0.31	2.66
Discussion	53	1.14	0.16	2.28	0.24	1.14
Mean diff. between Groups		0.01		1.51		1.52
VR approach	52	1.12	0.15	3.68	0.33	2.56
Discussion	53	1.14	0.16	2.28	0.24	1.14
Mean diff. between Groups		-0.02		1.40		1.42
BR approach	51	1.13	0.18	3.79	0.31	2.66
VR approach	52	1.12	0.15	3.68	0.33	2.56
Mean diff. between Groups		0.01		0.11		0.10

Source: Field Experiments, 2025. EECES: Endothermic & Exothermic Cognitive engagement Scale; : Mean; : Standard deviation

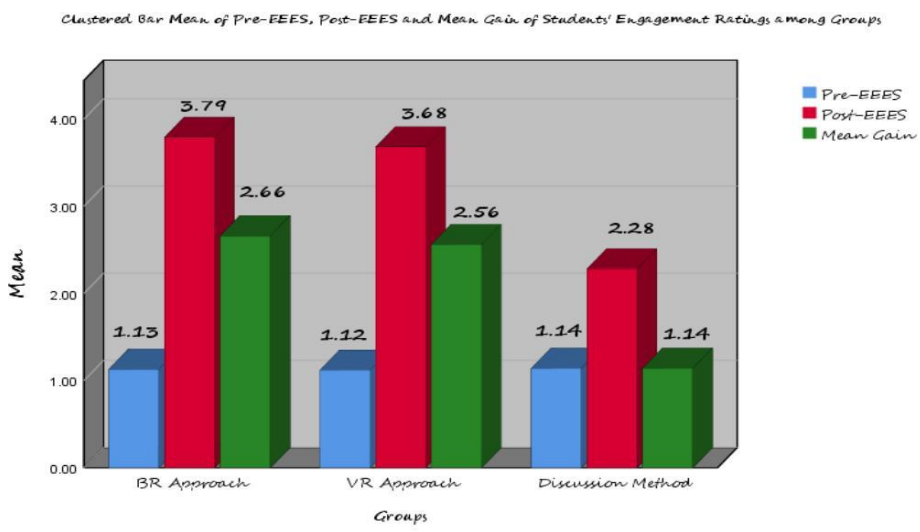

Fig. 1. Pre-EECES, Post-EECES, and mean gain in effect of BR approach, VR approach, and Discussion Method on Students' Cognitive engagement in Endothermic and Exothermic Reactions

The summary of the Pre-EECES, Post-EECES, and mean gain ratings of students taught endothermic and exothermic reactions using the BR approach, VR approach, and discussion method are represented in Figure 1. The data in Table 1 show that the gross mean difference between students in the BR approach and DM groups was 1.52 in favour of the BR approach. This implies that students in the BR group had higher cognitive engagement than students in the discussion group. Similarly, the overall mean difference between students in the VR group and DM groups was 1.42 in favour of VR. This implies that students in the VR approach group had higher cognitive engagement than those in the discussion group. Similarly, the overall mean difference between students in the BR approach and VR approach groups was 0.10. Nevertheless, the minor difference is in favour of the blended reality approach. This implies that students in the BR group had slightly higher cognitive engagement than their counterparts in the VR approach group. Lastly, students taught using the BR approach had slightly higher cognitive engagement than those taught using the VR approach. Meanwhile, students taught endothermic and exothermic reactions using a VR approach had a higher cognitive engagement rating than those taught using the discussion method.

3.2 Research Question 2

What is the interaction effect of treatments and gender on students' cognitive engagement rating in endothermic and exothermic reactions? Research question two is presented in Figure 1:

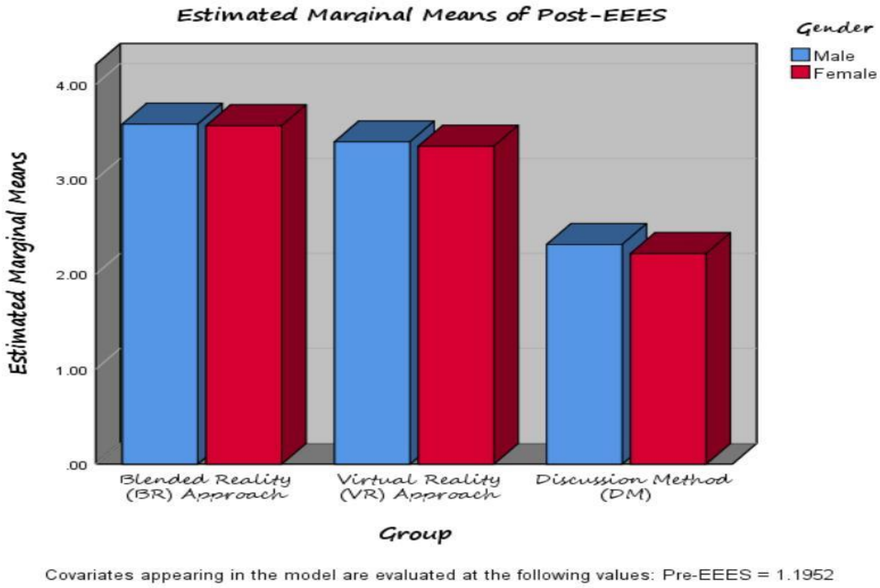

Fig. 2. Interaction bar chart of treatments and gender on students' cognitive engagement in endothermic and exothermic reactions

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Figure 2 presents a bar chart of the interaction effect of treatments and gender on the mean cognitive engagement rating of students in endothermic and exothermic reactions. The bar charts of each treatment are roughly the same height for both genders. In other words, the lines connecting the tops of the bars are roughly parallel, which suggests that the treatment effect is consistent across genders. Hence, the interaction effect of treatments and gender on students' cognitive engagement in endothermic and exothermic reactions was very minimal.

3.3 Research Question 3

What is the mean difference in higher-order thinking skills scores among students taught endothermic and exothermic reactions using the BR approach, VR approach, and discussion method? Table 2 and Figure 3 presented the answer to research question three

Table 2. Mean HOTS and Standard Deviation Scores of Students Taught Endothermic and Exothermic reactions using the BR approach, VR approach, and Discussion Method

Group	N	PRE- EEHOTST ~		POST- EEHOTST ~		Mean Gain within Group
BR approach	51	8.35	2.26	36.96	3.27	28.61
Discussion	53	8.37	2.24	22.21	3.14	13.84
Mean diff. between Groups		-0.02		14.75		14.77
VR approach	52	8.33	2.17	33.69	3.36	25.36
Discussion	53	8.37	2.24	22.21	3.14	13.84
Mean diff. between Groups		-0.04		11.48		11.52
BR approach	51	8.35	2.26	36.96	3.27	28.61
VR approach	52	8.33	2.17	33.69	3.36	25.36
Mean diff. between Groups		0.02		3.27		3.25

Source: Field Experiments, 2025. EEHOTST: Endothermic & Exothermic Higher-Order Thinking Skills Test; : Mean; : Standard deviation

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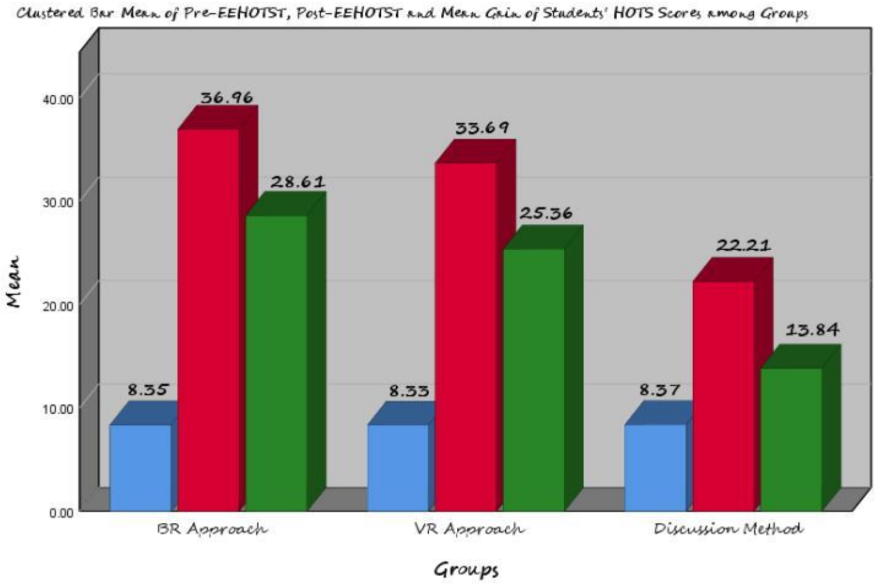

Fig. 3. Pre-EEHOTST, Post-EEHOTST, and Mean Gain in effect of the BR approach, VR approach, and Discussion Method on Students' Cognitive engagement in Endothermic and Exothermic Reactions

The summary of the Pre-EEHOTST, Post-EEHOTST, and mean gain scores of students taught endothermic and exothermic reactions using the BR approach, VR approach, and discussion method are represented in Figure 3. Table 2 reveals the mean higher-order thinking skills and standard deviation scores of students taught endothermic and exothermic reactions using the blended reality (BR) approach, virtual reality (VR) approach, and discussion method (DM) on a paired comparative basis. The data in Table 2 show that the gross mean difference between students in the BR approach and DM groups was 14.77 in favor of the BR approach. This implies that students in the BR group had higher-order thinking skills levels than students in the discussion group. Similarly, the gross mean difference between students in the VR group and DM group was 11.52 in favor of the VR approach. This suggests that students in the VR approach group had higher-order thinking skills than those in the discussion group. Similarly, the gross mean difference between students in the BR approach and VR approach groups was 3.25. However, the minor difference is in favour of the blended reality approach. This implies that students in the BR group had slightly higher-order thinking skills levels than their counterparts in the VR approach group. Lastly, students taught using the BR approach had slightly higher-order thinking skills levels than those taught using the VR approach. Meanwhile, students taught endothermic and exothermic reactions using a VR approach had higher-order thinking skills than those taught using the discussion method.

3.4 Research Question 4

What is the interaction effect of treatments and gender on students' higher-order thinking skills scores in endothermic and exothermic reactions? Research question four is presented in Figure 2:

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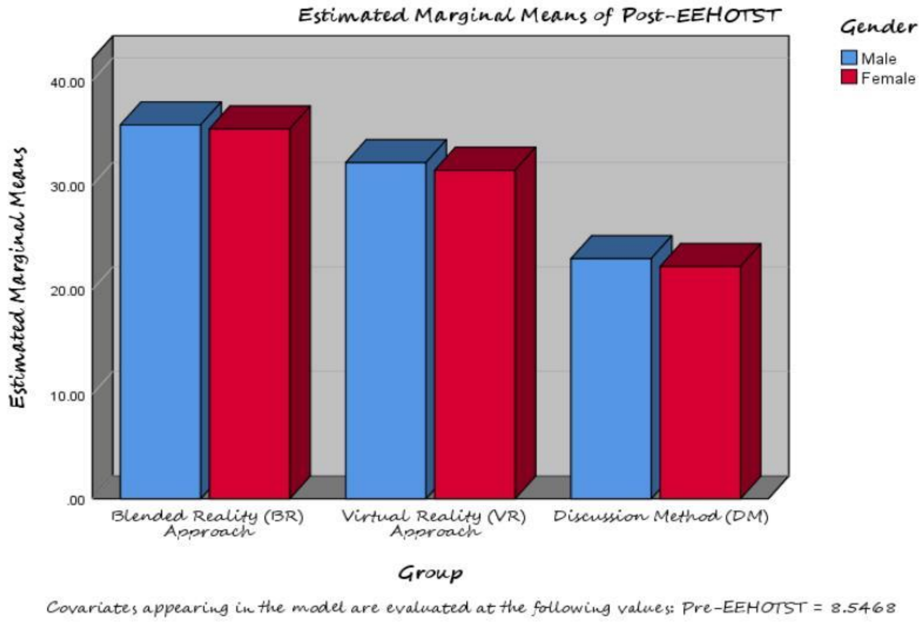

Fig. 4. Interaction bar chart of treatments and gender on students' HOTS level in endothermic and exothermic reactions

Figure 2 presents a bar chart of the interaction effect of treatments and gender on the mean higher-order thinking skills scores of students in endothermic and exothermic reactions. The bar charts of each treatment are roughly the same height for both genders. In other words, the lines connecting the tops of the bars are roughly parallel, which suggests that the treatment effect is consistent across genders. Hence, the interaction effect of treatments and gender on students' higher-order thinking skills in endothermic and exothermic reactions was very minimal.

3.5 Hypothesis 1

There is no significant difference in the cognitive engagement ratings of students taught endothermic and exothermic reactions using the BR approach, the VR approach, and the discussion method. Table 3 presents the test results of null hypothesis one.

Table 3. Two-Way ANCOVA for Mean Cognitive Engagement Rating of Students Taught Endothermic and Exothermic reactions using BR approach, VR approach, and Discussion Method

Source	Type III sum of squares		Mean Square	F	Sig.	Partial Eta Squared
Corrected model	854.059[a]	6	142.343	0981.003	.000	.862
Intercept	81.009	1	81.009	1170.001	.000	.651
TPreeces	.297	1	.297	.124	184	.000
Group	289.001	2	144.501	1505.004	.000	.901

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Gender	.087	1	.087	.975	.201	.002
Group*Gender	.052	2	.026	.040	.419	.001
Error	23.011	149	.081			
Total	1819.001	156				
Corrected Total	191.001	155				

a. R squared = .215 (Adjusted R Squared= .184)

Table 3 presents the two-way ANCOVA results for the mean cognitive engagement rating of students taught endothermic and exothermic reactions using the BR approach, VR approach, and discussion method (DM). The data in Table 3 reveal that the observed mean difference in the cognitive engagement rating among the groups was significant [F2, 155=1505.004, P<0.05]. Hence, the null hypothesis that there is no significant difference in the mean cognitive engagement ratings of students taught endothermic and exothermic reactions using the BR approach, VR approach, and discussion method was rejected. This suggests that there is a significant difference in the mean cognitive engagement scores among the groups. Meanwhile, the effect size was 0.901, as suggested by the corresponding partial eta squared value, which is considered a large effect size. This implies that 90.1% of the difference or variance in the cognitive engagement ratings among the groups was explained by the treatments. Thus, the difference in the cognitive engagement rating among the groups has a large statistical effect size.

Table 4. Bonferroni Post Hoc Comparison for Mean Cognitive Engagement Ratings of Students Taught Endothermic and Exothermic reactions using the BR approach, VR approach, and Discussion

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sign.
BR approach	DM	1.999*	.024	.000
VR approach	DM	1.976*	.024	.000
VR approach	BR	-.023	.024	.277

Source: Field Experiment, 2025; BR: Blended Reality VR: Visual Reality; DM: Discussion Method

Table 4 shows the Bonferroni post-hoc comparison for mean cognitive engagement ratings of students taught endothermic and exothermic reactions using the BR approach, VR approach, and Discussion method (DM). The results indicate that the mean difference (I-J) between the BR approach and DM is 1.999*, and this is significant at p<0.05. This implies that there is a significant difference in the mean cognitive engagement ratings between the students taught endothermic and exothermic reactions using the BR approach and those taught using DM in the BR approach class. Likewise, the results reveal that the mean difference (I-J) between the VR approach and DM is 1.976*, and this is significant at p<0.05. This implies that there is a significant difference in the mean cognitive engagement ratings between the students taught endothermic and exothermic reactions using the VR approach and those taught using

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DM in the VR approach class. However, the paired comparison of the VR approach and the BR approach showed a mean difference of -0.023, and this is not significant at p>0.05. This suggests no significant difference in the mean cognitive engagement ratings between students taught using the BR approach and the VR approach instructional approaches.

3.6 Hypothesis 2

There is no significant interaction effect of treatments and gender on the cognitive engagement ratings of students in endothermic and exothermic reactions. The data analysis of Table 3 is used to explain hypothesis 2.

The table presents a two-way ANCOVA for cognitive engagement of students taught endothermic and exothermic reactions using the BR approach, VR approach, and Discussion method (DM). The table presents the interaction effect of instructional strategies and gender. The data in Table 3 suggest that there is no significant interaction effect of treatments and gender on the mean cognitive engagement ratings of students in endothermic and exothermic reactions [F2, 155=.040, P<0.05]. The null hypothesis is therefore not rejected. Meanwhile, the effect size was 0.001 as indicated by the corresponding partial eta squared value, which is considered a small effect size. This implies that only 0.1% of the interaction in the cognitive engagement rating among groups was explained by treatments and gender. Hence, the interaction of treatments and gender on students' cognitive engagement has a small statistical effect size.

3.7 Hypothesis 3

There is no significant difference in the higher-order thinking skills scores of students taught endothermic and exothermic reactions using the BR approach, VR approach, and discussion method. Table 6 presents the test results of null hypothesis one.

Table 5. Two-Way ANCOVA for HOTS Scores of Students Taught Endothermic and Exothermic Reactions using the BR approach, the VR approach, and the Discussion Method

Source	Type III sum of squares		Mean Square	F	Sig.	Partial Eta Squared
Corrected model	9987.009[a]	6	3331.168	87.009	.000	.831
Intercept	17800.001	1	17800.001	751.090	.000	.601
TPreEEHOTST	679.009	1	679.009	43.004	.000	.076
Group	15990.001	2	7995.000	139.001	.000	.864
Gender	37.009	1	37.009	13.008	.109	.000
Group*Gender	23.119	2	11.556	.195	.119	.001
Error	8657.001	149	58.101			
Total	29297.001	156				
Corrected Total	18640.002	155				

R squared = .106 (Adjusted R Squared= .098) Source: Field Survey, 2025

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Table 5 presents the two-way ANCOVA results for the mean higher-order thinking skills scores of students taught endothermic and exothermic reactions using the BR approach, VR approach, and discussion method (DM). The data in Table 5 reveal that the observed mean difference in the higher-order thinking skills scores among the groups was significant [$F_{2, 155}$=139.001, P<0.05]. Hence, the null hypothesis that there is no significant difference in the mean higher-order thinking skills scores of students taught endothermic and exothermic reactions using the BR approach, VR approach, and discussion method (DM) was rejected. This implies that there is a significant difference in the mean higher-order thinking skills scores among the groups. Meanwhile, the effect size was 0.864, as indicated by the corresponding partial eta squared value, which is considered a large effect size. This implies that 86.4% of the difference or variance in the HOTS scores among the groups was explained by the treatments. Hence, the difference in the higher-order thinking skills scores among the groups has a large statistical effect size.

Table 6. Bonferroni Post Hoc Comparison for Mean HOTS Scores of Students Taught Endothermic and Exothermic Reactions using BR approach, VR approach, and DM

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sign.
BR approach	DM	13.299*	.352	.000
VR approach	DM	13.191*	.349	.000
VR approach	BR approach	-0.108	.358	.197

Source: Field Experiment, 2025; BR: Blended Reality VR: Visual Reality; DM: Discussion Method

Table 6 shows the Bonferroni post-hoc comparison for mean HOTS scores of students taught endothermic and exothermic reactions using the BR approach, the VR approach, and the Discussion method (DM). The results reveal that the mean difference (I-J) between the BR approach and DM is 13.299*, and this is significant at p<0.05. This implies that there is a significant difference in the mean HOTS scores between the students taught endothermic and exothermic reactions using the BR approach and those taught using DM in the commendation of students in the BR approach class. Likewise, the results reveal that the mean difference (I-J) between the VR approach and DM is 13.191*, and this is significant at p<0.05. This implies that there is a significant difference in the mean HOTS scores between the students taught endothermic and exothermic reactions using the VR approach and those taught using DM in the commendation of students in the VR approach class. However, the paired comparison of the VR approach and BR approach showed a mean difference of -0.108 and this is not significant at p>BR approach and VR approach instructional approaches.

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3.8 Hypothesis 4

There is no significant interaction effect of treatments and gender on the higher-order thinking skills scores of students in endothermic and exothermic reactions. The data analysis of Table 5, is used to explain hypothesis 4.

The table presents a two-way ANCOVA for HOTS scores of students taught endothermic and exothermic reactions using the BR approach, VR approach, and the Discussion method (DM). The table presents the interaction effect of instructional strategies and gender. The data in Table 3 reveal that there is no significant interaction effect of treatments and gender on the mean HOTS scores of students in endothermic and exothermic reactions [$F_{2, 155}$=.195, P<0.05]. The null hypothesis is therefore not rejected. Meanwhile, the effect size was 0.001 as suggested by the corresponding partial eta squared value, which is considered a small effect size. This implies that only 0.1% of the interaction in the higher-order thinking skills scores among groups was explained by treatments and gender. Hence, the interaction of treatments and gender on students' HOTS scores has a small statistical effect size.

4 Discussion

The study investigated if smart pedagogy, such as blended reality (BR) and virtual reality (VR) learning approaches, could enrich students' cognitive engagement and higher-order thinking skills (HOTS) level in the context of endothermic and exothermic reactions in the Dekina Local Government Area (LGA) of Kogi State, Nigeria. The findings of this study suggested that the difference in the cognitive engagement rating among students taught endothermic and exothermic reactions using the BR approach, VR approach, and discussion method was statistically significant. The post-hoc comparison for the cognitive engagement rating among the groups suggested that students taught endothermic and exothermic reactions using the BR approach had higher cognitive engagement than their counterparts taught using the discussion method. This is in line with Jibril, Issa, Onojah, Aderele, and Onojah (2022). concluded that blended learning enhanced students' academic performance in the educational technology concept than the conventional method. Likewise, this is in line with Ajayi, Ameh, and Alabi (2025). Findings that students' self-confidence and critical thinking ability were enhanced significantly in identifying physical and chemical changes when taught using technology-assisted constructivist approaches compared to their counterparts using the modified lecture method. The likely explanation for this outcome may be connected to the fact that the blended reality approach allows flexible, personalized learning experiences, better access to resources, and enriches a balance of face-to-face and digital instruction. The BR and VR approach helped the learners to explore concepts and generate investigations through engaging, understandable, hands-on technology tools and near-reality visual simulations when compared to the discussion method.

The post-hoc comparison for the cognitive engagement rating among the groups suggested that students taught endothermic and exothermic reactions using the VR approach had significantly higher cognitive engagement than their counterparts taught using the discussion method. This finding agrees with Danmal, Onansanya, Atanda,

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and Abdullahi (2024), who suggested that virtual reality (VR) technology effectively enhances STEM education for at-risk students at the secondary school level when compared with the traditional method of teaching. The post-hoc comparison for the cognitive engagement rating among the groups further revealed that the difference between students taught endothermic and exothermic reactions using the BR approach and those taught using the VR approach was not statistically significant. There was a scarcity of studies comparing the BR approach and VR approach on students' cognitive engagement in science subjects before. However, the likely explanation for this outcome may be attributed to the fact that both the BR approach and VR approach are used to help students in building a virtual, interactive learning environment close to the real environment through a variety of advanced technologies, and users can interact with the virtual environment to gain experience and knowledge, thus achieving the purpose of teaching.

The findings of this study revealed that the difference in the higher-order thinking skills scores among students taught endothermic and exothermic reactions using the BR approach, VR approach, and discussion method was statistically significant. The post-hoc comparison for the higher-order thinking skills scores among the groups revealed that students taught endothermic and exothermic reactions using the BR approach had significantly higher higher-order thinking skills than their counterparts taught using the discussion method. This is in line with Olatunde-Aiyedun and Adams (2022), who concluded that learners' achievement and retention in science are significantly improved by blended reality when compared to the lecture teaching method. The likely explanation for this outcome may be attributed to the fact that the smart pedagogy helped the learners to explore concepts and generate investigations using technology tools. Furthermore, the students are given the chance to express their schema and experience the science ideas behind the activity to satisfy their curiosity and thinking processes using technology tools and hands-on activities, compared to the discussion method.

The post-hoc comparison for the higher-order thinking skills scores among the groups also revealed that students taught endothermic and exothermic reactions using the VR approach had significantly higher higher-order thinking skills than those taught using the discussion method. This finding agrees with Ajayi (2023), who found that the VR approach was more effective in enhancing students' conceptual understanding and academic performance in the topic of moments in Physics than the conventional teaching method. The likely explanation for this outcome may be attributed to the fact that the use of a VR technology strategy provides a format for students to understand the nature of knowledge and the construction processes of knowledge using technology tools. The post-hoc comparison for the higher-order thinking skills scores among the groups further revealed that the difference between students taught endothermic and exothermic reactions using the BR approach and those taught using the VR approach was not statistically significant. One reason for the higher-order thinking skills of students taught using the BR approach and VR approach could be that they were able to reflect on, interpret, and search for solutions through exposure to real situations using technology tools when compared to students taught using a discussion group. BR and VR approaches integrates images, diagrams, audio, video, and animation in a complex way by computer, builds a teaching environment based on human cognitive characteristics, organizes and presents teaching knowledge, reflects the diversity and complexity of the form and content of knowledge information, provides students with a dynamic, open and free form of structured cognition, and is conducive to students' comprehensive mastery and application of the knowledge they have learned

The study revealed that the interaction effect between approach and gender on the cognitive engagement and higher-order thinking skills of students in endothermic and exothermic reactions is very minimal, but the ANCOVA test shows that the interaction effect was not significant, respectively. This implies that there was no significant interaction between approaches and gender on cognitive engagement and higher-order thinking skills of students in endothermic and exothermic reactions. Hence, either smart pedagogy, such as the BR approach or the VR approach, can be used successfully irrespective of gender in fostering students' cognitive engagement and higher-order thinking skills. In this case, there is no need for a separation of instructional approach for male and female students, since either the BR approach or the VR approach could be used successfully for the three groups.

5 Conclusion

Smart pedagogy creates flexible, personalized, and adaptive learning environments, enriching students' cognitive engagement and higher-order thinking skills. It was concluded that the students taught endothermic and exothermic reactions using smart pedagogy such as blended reality (BR) and virtual reality (VR) approaches had higher cognitive engagement and higher-order thinking skills in answering or solving problems related to endothermic and exothermic reactions, respectively, than those taught using the discussion method. Thus, recommendations were made:

1. Chemistry teachers should be encouraged to employ the use of the BR approach and VR approach to enrich students' cognitive engagement and higher-order thinking skills in the context of endothermic and exothermic reactions.
2. The Ministry of Education and professional bodies should organize workshops to sensitize chemistry teachers on the use of blended reality and virtual reality approaches to enrich students' cognitive engagement and higher-order thinking skills.
3. Ministry of Education and other educational stakeholders should advocate for the inclusion of smart pedagogy, such as blended reality and virtual reality approaches, in the curriculum.

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