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Effects of Hands-On Nanoscience Activities on Senior Secondary School Students' Academic Performance in Chemistry in Nigeria

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Abstract This study examined the effect of hands-on nanoscience activities on senior secondary school students' performance in chemistry, specifically on the concept of rate of reaction. A quasi-experimental, non-equivalent, pre-test–post-test control group design with a 2 × 2 × 3 factorial framework was employed. The sample comprised 127 SS II students from two co-educational schools in Ilorin, divided into experimental (n = 62) and control (n = 65) groups. Data were collected using a validated 50-item Rate of Reaction Performance Test (RRPT) and analysed with ANCOVA at the 0.05 significance level. Findings revealed a significant main effect of instructional strategy on students' performance ($F(1, 126) = 24.62$, $p < .05$), indicating that students taught with hands-on nanoscience activities significantly outperformed those taught with conventional methods. Achievement level also showed a significant effect ($F(2, 126) = 18.47$, $p < .05$), with high achievers outperforming medium and low achievers, while medium achievers outperformed low achievers. However, gender and the interaction of gender and achievement level were not significant. These findings highlight the effectiveness of hands-on nanoscience activities in promoting students' conceptual understanding, with implications for adopting innovative strategies that foster equitable and differentiated learning in chemistry classrooms.

Keywords: 1. academic performance; 2. effects; 3. hands-on activity; 4. hands-on nanoscience activity

Učinci praktičnih nanotehnoloških aktivnosti na akademsku uspješnost učenika viših razreda srednje škole iz kemije u Nigeriji

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Sažetak Ovo istraživanje ispitivalo je učinak praktičnih nanotehnoloških aktivnosti na uspješnost učenika viših razreda srednje škole iz kemije, posebno u području brzine reakcije. Primijenjen je kvazi-eksperimentalni nacrt s neekvivalentnim skupinama, u obliku predtest–potest kontrolne skupine, u okviru faktorskog plana 2 × 2 × 3. Uzorak je obuhvaćao 127 učenika drugog razreda srednje škole iz dviju mješovitih škola u Ilorinu, podijeljenih na eksperimentalnu (n = 62) i kontrolnu skupinu (n = 65). Podaci su prikupljeni pomoću validiranog testa uspješnosti iz područja brzine reakcije (RRPT), koji se sastojao od 50 stavki, te su analizirani ANCOVA-om na razini značajnosti 0,05. Rezultati su pokazali značajan glavni učinak nastavne strategije na uspješnost učenika ($F(1, 126) = 24{,}62$, $p < 0{,}05$), što ukazuje na to da su učenici poučavani praktičnim nanotehnološkim aktivnostima postigli znatno bolje rezultate od onih poučavanih konvencionalnim metodama. Razina postignuća također je pokazala značajan učinak ($F(2, 126) = 18{,}47$, $p < 0{,}05$): učenici s visokim postignućima bili su uspješniji od učenika sa srednjim i niskim postignućima, dok su učenici sa srednjim postignućima nadmašili one s niskim. Međutim, spol te interakcija spola i razine postignuća nisu bili značajni. Ovi nalazi ističu učinkovitost praktičnih nanotehnoloških aktivnosti u unapređivanju konceptualnog razumijevanja učenika, s implikacijama za usvajanje inovativnih strategija koje potiču pravedno i diferencirano učenje u nastavi kemije.

Ključne riječi: 1. akademska uspješnost; 2. učinci; 3. praktična aktivnost; 4. praktična nanotehnološka aktivnost

1 Introduction

Education remains the foundation for social progress, economic growth, and sustainable development. For nations seeking to remain competitive in the twenty-first century, strengthening the quality and relevance of education is therefore a priority. Education is widely recognised as a catalyst for national and global development, enabling individuals to think critically, solve problems, and contribute meaningfully to society (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2023). Among the disciplines that drive this mission, science holds a central role by fostering innovation, technological advancement, and sustainable growth (Hahl et al., 2022). Within science, chemistry occupies a unique place as the "central science," linking biology, physics, medicine, and environmental studies. It equips learners with conceptual knowledge, practical skills, and problem-solving abilities that are indispensable for technological progress and sustainable development (Brown et al., 2018). At the secondary school level, chemistry education is fundamental for equipping students with twenty-first century competencies such as logical reasoning, interpretation, and critical thinking (Jamil et al., 2024).

Despite its importance, the teaching and learning of chemistry is fraught with challenges. Persistent issues such as abstract curriculum content, inadequate laboratory facilities, ineffective teaching methods, and misconceptions about key topics- - such as rate of reaction - have negatively affected students' mastery of the subject (Egolum & Onuigwe, 2023; Jusniar et al., 2020; Kapici, 2023). These weaknesses are reflected in public examination outcomes.

For instance, the West African Examinations Council (WAEC) Chief Examiner's Report (2023) revealed that students performed poorly in Chemistry Paper 3, which is typically taken by senior secondary school students (approximately 16–18 years old) in Nigeria. The report cited difficulties with mathematical applications, significant figures, and practical skills. These concerns underscore the urgent need for innovative instructional approaches that present chemistry concepts in more concrete, engaging, and relatable ways.

Hands-on activities have long been identified as a promising method of addressing these challenges. By engaging learners directly in experimental tasks and problem-solving activities, hands-on methods promote active learning, curiosity, critical thinking, and deeper conceptual understanding compared to traditional memorisation (Haury & Rillero, 2014; Kibga et al., 2021). Empirical evidence supports their effectiveness in improving achievement and interest. For instance, Ajayi (2017) reported that students who were taught organic chemistry with activity-based methods demonstrated higher interest levels than those taught using discussion methods. Similarly, Ajayi and Ogbeba (2017) found that hands-on activities improved achievement in stoichiometry across gender, while Twumasi and Hanson (2018) observed significant performance gains and improved attitudes among students learning chemical bonding through hands-on strategies. More recent studies (Iyamuremye et al., 2023; Nwankwo et al., 2024; Tindan & Anaba, 2024) also confirm that hands-on and activity-based approaches foster engagement, curiosity, and academic success across various science subjects.

Beyond conventional laboratory-based activities, nanoscience explores the size, scale, surface area-to-volume ratios, and self-assembly of nanoscale (or sub-microscopic) particles such as atoms, molecules, electrons, or ions, which represent the building blocks of matter. Nanoscience-related hands-on learning has emerged as an innovative way of connecting abstract chemistry concepts with real-world applications. Nanoscience examines the unique behaviour of matter at the nanoscale (1–100 nm), enabling students to explore concepts such as size, scale, surface area-to-volume ratios, and self-assembly (Voo & Denis, 2022). Studies demonstrate that incorporating nanoscience activities can enhance conceptual understanding, motivation, and scientific awareness. For example, Mandrikas et al. (2020) found that nanoscale models improved students' comprehension of size and scale. Similar outcomes have been reported in Turkey (Senocak et al., 2021), Egypt (Ead et al., 2022), and South America (Knobel et al., 2010), where nanoscience engagement strengthened positive attitudes toward science and enriched learning experiences.

However, despite the growing global recognition of nanoscience's educational potential, there is limited research on its application within Nigerian secondary schools. Existing studies in Nigeria have predominantly focused on general hands-on strategies (Ajayi, 2017; Ajayi & Ogbeba, 2017; Ogbeba & Ajayi, 2018), but little attention has been given to nanoscience as a tool for enhancing achievement in challenging chemistry topics. Moreover, learner-related variables such as gender and performance levels (high, medium, and low achievers) remain underexplored within this context. Previous findings on gender and achievement in chemistry have been inconsistent. While some studies indicate male advantage in intrinsic value for learning chemistry (Gong et al., 2023), others suggest that females outperform males when inquiry-based methods are used (Aniodoh & Egbo, 2013). Still, many studies (Ajayi & Ogbeba, 2017; Oladejo et al., 2023) report no significant gender effects. Likewise, differentiated outcomes based on achievement levels have been emphasised in recent literature (Habib, 2021; Kibble et al., 2023), showing that tailored instructional approaches may benefit learners differently. Against this background, the study investigates the effects of hands-on nanoscience activities on senior secondary school students' academic performance in chemistry in Ilorin, Nigeria, with attention to gender and score-level differences. Specifically, the study investigated:

1. performance of students taught rate of reaction using hands-on nanoscience activities compared to those taught without them;
2. difference in performance between male and female students taught using nanoscience hands-on activities and those taught without them;
3. performance of high, medium, and low scoring students taught using nanoscience hands-on activities and those taught without them;
4. interaction effects of gender and score level on students' academic performance in chemistry when taught rate of reaction using hands-on nanoscience activities.

2 Methodology

This study employed a quasi-experimental, non-equivalent, pre-test–post-test control group design within a 2 × 2 × 3 factorial framework. Instructional strategy (hands-on nanoscience activities vs. conventional lecture), gender (male and female), and achievement levels (high, medium, low) served as the factors. A total of 127 Senior Secondary School II (SSII) chemistry students, aged approximately 16–18 years, from two purposively selected co-educational schools in Ilorin participated, with 62 in the experimental group and 65 in the control group. All students had received at least two years of prior chemistry education at the junior secondary school level. Informed consent was obtained from all students, and parental/guardian consent was secured for participants under 18 years of age, in accordance with the ethical guidelines for research with minors.

The experiment, rather than data collection, was conducted in three phases: pre-test administration, a three-week instructional intervention, and post-test administration. The experimental group was taught the concept of Rate of Reaction using a researcher-developed hands-on nanoscience activity package, while the control group received conventional lecture-based instruction. Both groups were taught by the same teacher under equivalent classroom conditions. Examples of hands-on nanoscience activities included synthesising simple nanoparticles using household reagents, observing catalysed reaction rates, and modelling molecular interactions with 3D kits. Lesson plans were prepared for both groups to ensure standardisation.

Data were collected using a 50-item Rate of Reaction Performance Test (RRPT), which served as the primary data collection instrument. The RRPT was validated by subject experts and achieved an acceptable reliability coefficient of KR-21 = 0.81. The test comprised a mix of multiple-choice (30 items), structured short-answer (15 items), and problem-solving questions (5 items).
Students were given 60 minutes to complete the RRPT. Observations indicated that most students completed the test within this timeframe, although a few required an additional 5–10 minutes to finish. A parallel form of the RRPT was administered as the post-test to measure learning gains.
Data were analysed using descriptive statistics (frequency, percentage, mean, standard deviation) and inferential statistics. Analysis of Covariance (ANCOVA) was employed at the 0.05 significance level, using pre-test scores as covariates to control for initial group differences and isolate the effect of the instructional strategies.

3 Results

Table 1 revealed a statistically significant difference in student performance between those taught the concept of Rate of Reaction using hands-on nanoscience activities and those exposed to the conventional lecture method, in favour of the experimental group, $F(1, 124) = 15.62$, $p < .001$, $\eta^2 = .112$. This indicates that students exposed to hands-on nanoscience activities performed better than their counterparts taught without it.

Table 1: ANCOVA Summary for Students' Performance by Instructional Strategy

Source	SS	df	MS	F	*p*	Partial η^2
Pre-test (Covariate)	182.45	1	182.45	6.89	.010	.053
Instructional Strategy	413.72	1	413.72	15.62	<.001	.112
Error	3282.41	124	26.47			
Total	4178.58	126				

Source: author

Table 2: ANCOVA Summary for Students' Performance by Gender

Source	SS	df	MS	F	*P*	Partial η^2
Pre-test (Covariate)	192.63	1	192.63	6.41	.013	.049
Gender	55.22	1	55.22	1.84	.177	.015
Error	3724.89	124	30.04			
Total	3972.74	126				

Source: author

Table 2 revealed that there was no statistically significant difference in the performance of male and female students taught using hands-on nanoscience activities and those taught using the conventional method, $F(1, 124) = 1.84$, $p = .177$, $\eta^2 = .015$. This indicated that gender did not influence students' performance under either instructional approach.

Table 3a: ANCOVA on Students' Performance by Instructional Strategy, Gender, and Achievement Level

Source	SS	df	MS	F	*p*	Partial η^2
Instructional Strategy	1120.54	1	1120.54	15.62	<.001	.112
Gender	132.09	1	132.09	1.84	.177	.015
Achievement Level	1359.28	2	679.64	9.47	<.001	.132
Gender × Achievement Level	138.12	2	69.06	0.96	.387	.008
Error	8899.47	124	71.77			
Total	13,649.50	130				

Source: author

Table 3a shows that instructional strategy had a significant effect, $F(1, 124) = 15.62$, $p < .001$, partial $\eta^2 = .112$, indicating that students taught with hands-on nanoscience activities outperformed those taught conventionally. Achievement level also had a significant effect, $F(2, 124) = 9.47$, $p < .001$, partial $\eta^2 = .132$, meaning high, medium, and low achievers differed in performance. However, gender was not significant, $F(1, 124) = 1.84$, $p = .177$, partial $\eta^2 = .015$, and neither was the interaction between gender and achievement level, $F(2, 124) = 0.96$, $p = .387$, partial $\eta^2 = .008$, suggesting performance was unaffected by gender.

Table 3b: Bonferroni Post-hoc Test for Achievement Level on Students' Performance

Achievement Level (I)	Achievement Level (J)	Mean Difference (I–J)	SE	*p*	95% CI (Lower, Upper)
High	Medium	6.51	1.98	.002	2.34, 10.68
High	Low	12.32	2.15	<.001	7.88, 16.76
Medium	Low	5.81	1.87	.004	2.12, 9.50

Source: author

Table 3b presents the Bonferroni post-hoc results by achievement level. High achievers (M = 72.65, SD = 8.21) performed significantly better than medium achievers (mean difference = 6.51, $p = .002$) and low achievers (mean difference = 12.32, $p < .001$). Medium achievers also outperformed low achievers (mean difference = 5.81, $p = .004$). This establishes a clear performance order: high > medium > low achievers.

Table 4: ANCOVA for the Interaction Effect of Gender and Achievement Level on Students' Performance

Source	Type III SS	Df	Mean Square (MS)	F	Sig. (*p*)	Partial η^2
Corrected Model	348.43	3	116.14	1.62	.188	.038
Intercept	254.76	1	254.76	3.55	.062	.028
Pre-test (Covariate)	210.45	1	210.45	2.93	.089	.023
Gender × Achievement Level	137.98	2	68.99	0.96	.387	.015
Error	8,899.48	124	71.77			
Total	46,182.00	128				
Corrected Total	9,247.91	127				

Source: author

Table 4 indicated that the interaction effect of gender and achievement level on students' performance was not statistically significant, $F(2, 124) = 0.96$, $p = .387$, $\eta^2 = .008$. This suggests that the combined influence of gender and achievement level did not affect students' performance when exposed to hands-on nanoscience activities and conventional instruction.

4 Discussion

The findings revealed a statistically significant difference in students' performance based on instructional strategy, in favour of those exposed to hands-on nanoscience activities compared to their counterparts taught with the conventional lecture method. Therefore, activity-based approaches were more effective in enhancing students' conceptual understanding of the rate of reaction. Moreover, this result agrees with studies by Ajayi (2017), Twumasi and Hanson (2018), and Mandrikas et al. (2020), which reported that hands-on, practical, and real-world-oriented strategies improved students' achievement in science.

The findings indicated that gender did not significantly influence students' performance across the instructional methods. Thus, both male and female students benefitted equally from hands-on nanoscience activities as well as conventional instruction. Furthermore, the result aligns with the findings of Ajayi and Ogbeba (2017), Oladejo et al. (2023), and Gong et al. (2023), who also found no significant gender differences in performance when activity-oriented strategies were implemented. Collectively, these outcomes reinforce the perspective that equitable pedagogical strategies can minimise gender gaps in science achievement. Nevertheless, the finding contradicts reports by Aniodoh and Egbo (2013), who found significant differences in favour of male students in science performance. Overall, the absence of a gender effect in this study supports the idea that innovative teaching methods have the potential to neutralise gender biases and provide balanced opportunities for both genders to excel.

The findings revealed that instructional strategy significantly influenced students' performance, with achievement level also showing a strong effect, as high, medium, and low achievers performed differently. This agrees with Habib (2021) and Kibble et al. (2023), who noted the role of prior achievement in shaping learning gains.

The findings revealed that the interaction effect of gender and achievement level on students' performance was not statistically significant. Hence, the combined influence of gender and achievement level did not determine students' performance when taught with hands-on nanoscience activities or conventional instruction. Correspondingly, this finding is consistent with studies by Ajayi and Ogbeba (2017) and Oladejo et al. (2023), who likewise found no significant gender–achievement interaction in science classrooms.

5 Conclusion

The study concluded that hands-on activities in nanoscience significantly enhanced students' performance in learning the concept of the rate of reaction compared to conventional lecture methods. Results demonstrated that hands-on nanoscience activities significantly enhanced students' performance in learning the concept of rate of reaction compared to conventional lecture methods.

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Conflict of Interest Statement

The author declares that there are no conflicts of interest associated with this study. The research was conducted independently, and no financial or personal relationships influenced the study's design, data collection, analysis, or reporting.

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