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Differentiated instruction improves interest, cognitive engagement and achievement in Chemistry

La instrucción diferenciada mejora el interés, el compromiso cognitivo y el rendimiento en Química

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Abstract

It is well known that differentiated instruction (DI) improves learning outcomes for students. However, few studies have analysed the simultaneous effects of differentiated instruction on interest, cognitive engagement and performance in Chemistry, particularly in relation to different levels of achievement. Therefore, this study investigated the effects of DI on interest, cognitive engagement and performance among high- and low-achieving students in Chemistry. Guided by two research questions and their corresponding hypotheses, the study employed a quasi-experimental pre-test-post-test design with a non-equivalent control group comprising 124 secondary school Chemistry students. The Chemistry Interest Scale (CIS), the Cognitive Engagement in Chemistry Scale (CCES) and the Chemistry Achievement Test (CAT) were validated and used to collect data. Quade's ANCOVA and the adjusted mean were used for data analysis. The results showed that DI was significantly more effective than the lecture method in increasing students' interest, cognitive engagement and performance. Furthermore, it was observed that DI benefits high- and low-achieving students equally. Therefore, it is recommended that DI be adopted in secondary school Chemistry classrooms to effectively support diverse student populations and improve key learning outcomes across all performance levels.

Keywords: differentiated instruction; cognitive engagement; chemistry achievement; achievement levels.

Resumen

Es conocido que la instrucción diferenciada (ID) mejora los resultados de aprendizaje del alumnado. Sin embargo, son escasos los estudios que han analizado los efectos simultáneos de la instrucción diferenciada sobre el interés, la implicación cognitiva y el rendimiento en Química, especialmente en función de los distintos niveles de rendimiento. Por ello, este estudio investigó los efectos de la ID sobre el interés, la implicación cognitiva y el rendimiento de estudiantes con alto y bajo rendimiento en Química. Guiado por dos preguntas de investigación y sus hipótesis correspondientes, el estudio empleó un diseño cuasi-experimental de pretest-posttest con un grupo de control no equivalente compuesto por 124 estudiantes de Química de secundaria. Se validaron y utilizaron para la recopilación de datos la Escala de Interés por la Química (CIS), la Escala de Compromiso Cognitivo en Química (CCES) y la Prueba de Rendimiento en Química (CAT). Para el análisis de datos se utilizaron el ANCOVA de Quade y la media ajustada. Los resultados mostraron que la ID fue significativamente más eficaz que el método de clase magistral para aumentar el interés, el compromiso cognitivo y el rendimiento del alumnado. Además, se observó que la ID beneficia por igual a estudiantes de alto y bajo rendimiento. Por tanto, se recomienda la adopción de la ID en las clases de Química de secundaria para apoyar de manera eficaz a una población estudiantil diversa y mejorar los resultados clave del aprendizaje en todos los niveles de rendimiento.

Palabras clave: instrucción diferenciada; compromiso cognitivo; rendimiento en química; niveles de rendimiento.

Introduction

In recent years, there have been calls for inclusive and adaptive teaching practices in the educational systems of the world, especially in countries with inadequate educational resources, cultural peculiarities and population diversity. Building on this, Am et al. (2023) emphasise the significance of these constraints in influencing students' engagement and instructional effectiveness in a systematic review. These insights align with Onyishi and Sefotho (2020), who argue that there is an increasing need to address the educational challenges faced by students in Africa, particularly in Nigeria, to meet the diverse needs of learners across school subjects such as Chemistry. Chemistry is regarded as an abstract and difficult subject due to its heavy memory demands to process the interconnections between macroscopic phenomena, submicroscopic particle behaviour, and symbolic representations (Permatasari et al., 2022). Because many Chemical ideas are particulate and model-dependent, they exceed students' mental capacity. According to cognitive load theory, human working memory is strained when intended tasks require processing more information than it can handle (Sweller, 1994), leading to misconceptions, cognitive overload, and a disconnected experience (Hartman et al., 2022; Tümay, 2016). Similar to this theoretical insight, Ezeudu et al. (2019) note that secondary school students in Nigeria perceive Chemistry as an abstract and difficult subject, leading to a lack of interest, engagement, and poor learning outcomes. As a result, researchers have begun to explore innovative approaches, including Differentiated Instruction (DI), to boost students' interest, cognitive engagement, and achievement.

Differentiated learning, according to Songer et al. (2020), is a strategy aimed at accommodating diversity in learners' readiness, interests, and learning profiles. As a pedagogical framework, it provides teachers with guidance on planning and delivering instruction using and adjusting to various instructional strategies to optimise students' individual needs and abilities (Yusnidar et al., 2024). Hence, it includes various strategies a teacher may employ to enhance students' content, process, product, and learning environment through tailored support, as highlighted by Vygotsky's (1978) theory and supported by empirical evidence in foreign language education (Kahmann et al., 2024). Suson et al. (2020) emphasised that DI takes into account each student's readiness to learn, variations, diversity, and the details of the learning process to ensure they achieve the maximum level of achievement. Therefore, DI could address the needs of low-achieving students and meet the demands, interests, needs, and challenges of high-achieving students. Although studies have shown the ability of DI to increase students' motivation, self-confidence, interest, and thinking abilities (Abdel qader, 2019; Al-Shehri, 2020), Hu (2024) argues that its effectiveness can vary based on subject, teachers' expertise, and classroom context. The principles of DI (Tomlinson, 2005; Suson et al., 2020; Neuvirthova & Gadusova, 2021; Goyibova et al., 2025) applied in the study are active student participation, where students ask questions without fear, work in flexible groups, and interact with their peers. It also encompasses assessment for learning, respects diversity, and fosters collaboration between teachers and students to improve their interests and learning outcomes.

According to Schiefele (2012), interest is an emotional and value-based association that a learner attaches to a subject to predict comprehension, persistence and academic achievement. It can be grouped into situational interest and individual interest. While situational interest refers to a temporary emotional state aroused by a specific task, individual interest involves a stable affective feeling attached to a domain or subject, leading to long-term engagement. For Hidi (2006), interest is a motivational variable that increases attention and concentration during an interaction between a person and an idea or an object of interest. As a unique psychological state, it increases one's predisposition to re-engage with a particular idea or task. Together, these conceptualisations affirm that interest is a motivational construct, highlighting its contribution to learning outcomes within broader motivational frameworks (Urhahne & Wijnia, 2023) and its reciprocal relationship with academic achievement (Vu et al., 2024). Therefore, Interest is a cognitive-affective construct that develops progressively and enhances attention, engagement, information processing, and the willingness to invest time and effort. It is value-related and deepens positive feelings of a learner in a particular subject area, thereby enhancing learners' academic outcomes and motivation. Cognitive engagement, on the other hand, describes students' mental effort, investment, and interest directed towards learning, understanding, the use of self-regulated strategies, motivation, and goal setting (Pohl, 2020). It is the rate at which students are capable and eager to engage in a current educational task. This involves how long students persevere and how much effort they are willing to put into the assignment (Antúnez et al., 2020), which can lead to misconceptions and mental strain, as emphasised by the cognitive load theory (Sweller, 1994). Improving students' cognition through collaboration is important in learning, especially in Nigeria, where rote memorisation is predominantly present in science classrooms. Therefore, teachers can use differentiated instruction to enhance cognitive engagement (Saputri et al., 2023; Lavania & Nor, 2020) by providing appropriate tasks that meet students' individual needs.

While acknowledging the significance of interest and cognitive engagement in ensuring meaningful learning, the place of achievement as the fulcrum for assessing educational effectiveness remains. Academic achievement, according to Schunk et al. (2014), represents the cumulative outcome of sustained motivational and engagement processes. Engagement-based learning models indicate that students' interest promotes deeper cognitive engagement, which, in turn, supports persistence, effective learning strategies, and improved achievement outcomes (Hidi & Renninger, 2006). In Nigeria, the West African Examination Council Chief examiners' reports have demonstrated subpar and fluctuating chemistry results (WAEC, 2019-2023). Similarly, this poor achievement in Chemistry has been reported in developing countries, including Somalia (Hashi et al., 2025), South Africa (Chakawodza et al., 2025, Ghana (Mensah, 2023), and Tanzania (Ochieng et al., 2019). Within an engagement framework, DI is expected to influence achievement indirectly by enhancing interest, learning styles, readiness levels, and cognitive engagement (Tomlinson, 2014). The use of this framework results in achievement gains for both high- and low-achieving students. In this study, low achievers are students who find it difficult to learn Chemistry, whereas high achievers are academically sound. Low achievers are often characterised by the following: lower proficiency, poor language use, unsuccessful learners, dependence on teachers or peers, lack of motivation, and comprehension difficulties. Whereas high achievers are proactive, pay attention, plan, practice, set goals, identify information and ensure self-monitoring and evaluation (Normazidah et al., 2012; Samperio, 2019). The categorisation of high and low achievers was empirically operationalised using the pretest designed by the researchers. Based on the assessment practice recommended by Marsden and Torgerson (2012), the group mean score of the pretest was utilised. Hence, students with a score equal to or above the mean were considered high achievers, while those below the mean were classified as low achievers. The use of DI could ensure that students achieve the needed learning objectives regardless of prior abilities. Moreover, the importance of examining students by their achievement is necessary not just in Nigeria but in African countries where disparity in academic achievement is linked to culture, lack of expertise, large class size, socio-economic status of parents, language proficiency and inadequate science, technology, engineering and mathematics (STEM) educational resources.

Previous studies on DI have been conducted in different areas of learning. Empirical studies show that DI significantly improve self-directed learning readiness in mathematics and science classrooms (Özüdoğru, 2022), while also encouraging students' participation, motivation, and academic achievement (Özüdoğru, 2022; Magableh & Abdullah, 2020; Al-Rashidi, 2015). For Al-Shehri (2020), DI also improve students' self-concept and parallel thinking and critical thinking skills. However, the findings of Bal (2023), conducted with Turkish secondary school students, indicate mixed results and reveal that although DI increases students' mathematics achievement, it has no impact on their attitude towards the subject. Moreover, a meta-analysis and systematic review of studies on the effectiveness of DI in learning show that, compared to traditional instruction, DI yields a moderate to large effect size, ranging from +.509 to +.741 and improves learning outcomes, cognitive skills, and critical thinking (Hu, 2024; Am et al., 2023). However, its effectiveness varies across countries, school subjects, grade levels, educational levels, and teachers' conceptualisations (Smale-Jacobse et al., 2019; Am et al., 2023). As Metu and Ugwuanyi (2024) reported, teachers' creativity, as demonstrated through problem-solving strategies and the design of tasks based on students' strengths, as is evident in DI, significantly predicts students' achievement.

Despite the theoretical appeal of DI, empirical studies on its implementation and impact in Chemistry classrooms in Nigeria remain underexplored. Moreover, previous studies focused on other educational disciplines and were mostly conducted outside the context of this study, making it difficult to generalise the findings to the Nigerian setting due to its peculiarities. Moreover, the persistent use of the lecture method (LM) in Nigerian secondary schools often fails to accommodate students' diversity, potentially limiting engagement, interest, and achievement in school subjects. DI could offer a promising strategy for addressing this issue and meeting the unique needs and abilities of each student, and examining its effects across students' achievement levels (high and low achievers) in chemistry provides new insights into DI's potential in a subject deemed abstract and difficult for students.

This study sought to fill that gap as its objectives include determining the: a) Effect of DI and LM on secondary school students' interest, cognitive engagement, and achievement in Chemistry; and b) Effect of DI on high- and low-achieving students' interest, cognitive engagement, and achievement in Chemistry.

Method

A quasi-experimental pretest-posttest design with a non-equivalent control group was used because it was not possible to randomly assign intact classes without disrupting academic programs in the participating schools. This design has also been used in similar studies (Al-Rashidi, 2015; Al-Shehri, 2020). Quade's ANCOVA was used to statistically control for baseline differences in pretest scores between the treatment and control groups, as the study used intact classes. This approach ensures that the observed differences in posttest scores are attributed to the treatment rather than to pre-existing group differences. Therefore, the pretest served as a covariate to the posttest.

Participants

The participants were 124 senior secondary two (SSII) students from four public schools, selected via purposive sampling in the Otuocha Education Zone, Anambra State, Nigeria. Purposive sampling was used to select schools with research assistants who had similar academic qualifications and teaching experience, to ensure consistency in intervention delivery. Also, the four public schools used in this study were located in different parts of the education zone to avoid treatment diffusion. They included 55 males and 69 females, aged 14–18 years (*M* = 16.17, *SD* = 1.26). Participants belonged to two ethnic groups, Igbo (85 students) and Igala (39 students). An a priori power analysis was conducted with G*Power 3.1 (Faul et al., 2009) to determine the adequacy of the sample size. Parameters: ANCOVA with fixed effects, alpha = .05, power = .80, medium effect size (*f* = .30). Based on these parameters (Cohen, 1988), a sample size of 111 was identified as sufficient; 124 were recruited. A medium effect size was used because recent systematic reviews (Am et al., 2023; Smale-Jacobse et al., 2019) indicate that DI yields a moderate to large effect size in the educational context, and Cohen (1988) recommends it for situations with prior mixed findings. The experimental group consisted of 57 students, and the control group comprised 67 students.

Instruments

The instruments, which contained demographic data of gender and age, were given to the participants to measure students' interest, cognitive engagement, and Chemistry achievement: the Chemistry Interest Scale (CIS), the Chemistry Cognitive Engagement Scale (CCES) and the Chemistry Achievement Test (CAT). The three instruments were subjected to face and content validation by three experts in Chemistry education, Psychology education and measurement and evaluation. Moreover, cultural and contextual adaptations guided by Cruchinho et al. (2024) and Nascimento and Correia (2025) were applied to the CIS and CCES, as they were originally developed in American contexts. Three experts conducted a review of the instruments to examine the cultural fit, relevance, clarity, and appropriateness of the items to the Nigerian context. Two language experts conducted the back translation to ensure conceptual fidelity and to reword items in line with British English. The researchers then harmonised the experts' ideas and, using 30 SSII students, conducted pre-testing at a school similar to the study sample.

Chemistry Interest Scale (CIS)

The CIS was adapted from Knekta et al. (2020). The 30 items consisted of positively worded items, rated on a 4-point Likert scale with response options of Strongly Agree (4), Agree (3), Disagree (2), and Strongly Disagree (1), and selected from the original instrument. The instrument has demonstrated acceptable construct validity and reliability and has been applied among secondary school science students (Senina & Manguilimotan, 2025). Also, an exploratory factor analysis (EFA) of the original instrument revealed a strong relationship between the construct and its items, while the confirmatory factor analysis (CFA) revealed excellent model fit values (CFI = .96; loading = .62-.88; RMSEA = .045-.06). Cronbach's alpha reliability indices were high for the original scale at (.89-.92; CR = .85-.90) while .85 for the CIS. Among other items, "Being involved in biology classes puts me in a good mood" was reworded as “Taking part in Chemistry lessons usually puts me in a good mood.” The highest possible score is 120, while the lowest score is 30.

Chemistry Cognitive Engagement Scale (CCES)

The researchers adapted the Chemistry Cognitive Engagement Scale (CCES) from Barlow (2019) to measure students’ cognitive engagement in Chemistry. The CCES comprised eighteen items with five dimensions, namely interactivity with peers, constructive note-taking, active note-taking, active processing and passive processing, which were holistically analysed. This was done because Pohl (2020) confirms the need to unify the domains of cognitive engagement as a single underlying latent trait rather than separate subdimensions. This instrument was selected because it is theoretically grounded and has demonstrated acceptable validity through EFA, which showed strong construct-item relationships and excellent CFA model fit (CFI = .965, RMSEA = .041; loadings = .531-.884; CR = .681-.861). Cronbach's alpha revealed strong dependability indices (.702-.818) for the five loaded factors and yielded an alpha of .80 for the CCES. The present study reworded some of the items, for example, from “I justify my perspective to others when discussing course content” to “I justify my understanding of Chemistry ideas when discussing them with others.” The instrument was also evaluated on a scale of 1 to 4; hence, we had the highest score of 72 and the lowest score of 18.

Chemistry Achievement Test (CAT)

The CAT was developed by the researchers to evaluate students’ academic achievement in Chemistry. It consisted of 25 multiple-choice questions, each with four alternatives (A-D), with each correct answer awarded 2 marks and each incorrect answer 0. Therefore, the highest score is 50 while the lowest score is 0. The questions were based on the heading “Thermodynamics and Chemical reactions”, which is a component of the SSII scheme of work. The contents validity of CAT was ensured as the multiple-choice questions were prepared in accordance with the revised Bloom’s taxonomy and based on the representativeness of the curriculum contents, which covers the following contents: energy changes in chemical reactions and chemical equilibrium (44%), Heat of reaction (20%), and energetics of reactions (36%); and the cognitive objectives of remembering (32%), understanding (24%), applying (20%), analyzing (8%), evaluating (12%), and creating (4%). The CAT, including the lesson plan and table of specifications, were also validated by the three experts mentioned earlier. Meanwhile, the internal consistency of the CAT was determined using the Kuder-Richardson (KR-20), yielding a reliability index of .88.

Procedure

Before the commencement of the study, the researchers obtained ethical clearance (REC/DSE/NAU/24/0082) from the Research Ethics Committee of the Department of Science Education at Nnamdi Azikiwe University, Awka. The researchers briefed the research assistants (regular Chemistry teachers with Bachelor's honours and eleven to fourteen years of teaching experience) on the objectives of the study. This briefing lasted for three days within the first week, using the researchers' developed lesson plans for both the experimental and control groups. For the experimental group, the first three days of the first week were spent training research assistants in DI, including its concepts, implementation steps, practice sessions, demonstrations, and feedback, while the last two days were used to administer the pretest to both groups to determine students' pre-existing knowledge. The pre-test scores served as covariates and were used to classify students as low or high achievers (Marsden & Torgerson, 2012). The treatment lasted from the 2nd to the 5th week, with the experimental group taught using the DI strategy and the control group exposed to the lecture method.

The pedagogical foundations of DI were utilised for the experimental group, including clear objectives, readiness assessment, structured practice, flexible support, peer interaction and collaborative learning. Each subgroup received specific materials: while high achievers were provided with open-ended problems and extension tasks, the low achievers received worked examples, guided notes and teachers' support. In line with the DI principles, the teacher introduces the learning objectives and provides a brief overview of the topic. Students are then placed in their groups: high-achievers are assigned complex tasks with open-ended problems, extension activities, and opportunities to explore independently, while low-achievers are provided with worked examples, guided notes, and scaffolded prompts. Through collaborative activities and guided practices during instruction, the teacher and sometimes the high achievers also provided further support tailored to low-achieving students' strengths and weaknesses, until they were competent enough to work independently. At intervals, the learning materials for the groups were changed to more complex ones as students progressed within their Zone of Proximal Development (ZPD). Students were considered to be operating within the ZPD if they demonstrated improvement in task performance, formative assessments, and their ability to independently carry out procedures or achieve the learning objectives. An observation checklist based on the intervention steps was used to confirm teachers' implementation fidelity of the treatment. On the other hand, students in the control group received the same content, learning objectives, time allocation, and assessments as the experimental group, but were taught solely through the lecture method. After four weeks of content delivery, the post-test was administered to the experimental and control groups using the CIS, CCES and CAT. The researchers marked and recorded the pretest and post-test scripts of the instruments for data analysis.

Data analysis

The statistical data analysis was done using the IBM SPSS Statistics, Version 28.0, statistical software. Adjusted mean was used to answer the research questions, while Quade's Analysis of Covariance (ANCOVA) was used to test the hypotheses at a .05 level of significance. The Partial Eta Squared (ηp^2) was calculated to determine the magnitude of the effect of Differentiated Instruction (DI) on the dependent variables.

Results

The assumptions underlying ANCOVA were examined before the analysis. The results indicated that homogeneity of variance was satisfied; however, the assumptions of normality, linearity between the covariate and dependent variable across groups, and homogeneity of regression slopes were violated. These violations suggest that the score variability between the groups was not comparable, and that the use of a parametric ANCOVA was inappropriate for adjusting for initial differences and isolating the treatment effect. Consequently, a non-parametric Quade's analysis of covariance (ANCOVA), which was empirically supported by Omar et al. (2025), was used.

Effect of DI and LM on secondary school students' interest, cognitive engagement, and achievement in Chemistry

The results of the effect of DI and LM on secondary school students' interest, cognitive engagement and achievement in Chemistry are presented in Table 1. Table 1 shows that the adjusted mean interest score of the students taught Chemistry with the DI (M_{adj} = 101.44, *SE* = .89) was significantly higher than those taught with the lecture method (M_{adj} = 80.30, *SE* = .82, *F*(1,122) = 349.26, *p*<.001, ηp^2 = .74). Therefore, there is a significant difference between the adjusted mean interest rating of students taught Chemistry using DI and LM, in favour of students taught using DI. The partial eta squared (.74) reveals a large effect size, indicating that the experimental strategy accounts for approximately 74% of the variation in students' interest in chemistry.

The findings in Table 1 indicate that the adjusted mean cognitive engagement score of the students taught Chemistry with the DI (M_{adj} = 57.47, *SE* = .57) was significantly higher than those taught with the lecture method (M_{adj} = 48.45, *SE* = .52, *F*(1,122) = 143.85, *p*<.001, ηp^2 = .54). Therefore, there is a significant difference between the adjusted mean cognitive engagement scores of students taught Chemistry using DI and LM, favouring those taught using DI. The experimental strategy accounts for a large effect size, approximately 54% of the variation in students' cognitive engagement in Chemistry, as indicated by the partial eta-square of .54.

The effect of DI and LM on students' chemistry achievement is also shown in Table 1, where the adjusted mean achievement score of students taught Chemistry with the DI (M_{adj} = 42.52, *SE* = .51) was significantly higher than those taught with the lecture method (M_{adj} = 32.03, *SE* = .47): $F[(1,122) = 215.93, p <. 001, \eta p^2 = .64)$. Therefore, students taught Chemistry using DI and LM show a large effect size and differ significantly, favouring students taught using DI. According to the partial eta-square value of .64, the experimental strategy accounts for approximately 64% of the variation in students' chemistry achievement. The large effect sizes observed for DI's effect on students' interest, cognitive engagement, and achievement in Chemistry exceed the conventional threshold for a large effect ($\eta p^2 \geq 0.14$) as recommended by Cohen (1988). However, the finding is consistent with a systematic meta-analysis by Am et al. (2023), which revealed a large overall effect size for DI on students' learning outcomes and, invariably, on interest and cognitive engagement.

Table 1

Quade's rank ANCOVA for the effect of instructional strategy (DI vs. LM) on students' interest, cognitive engagement, and achievement

Variable	Group	*n*	Pretest *M (SD)*	Posttest *M (SD)*	M_{adj}	*SE*	95% *CI*	*F*(1,122)	ηp^2
Interest	DI	57	68.18 (9.19)	101.39 (5.69)	101.44	.89	[99.67,103.20]	349.26***	.74
	LM	67	69.28 (8.67)	80.34 (7.52)	80.30	.82	[78.67,81.93]		
Cognitive engagement	DI	57	43.60 (7.35)	58.14 (7.63)	57.47	.57	[56.35,58.60]	143.85***	.54
	LM	67	42.30 (7.77)	47.88 (9.00)	48.45	.52	[47.41,49.49]		
Achievement	DI	57	24.11 (4.63)	42.25 (3.03)	42.52	.51	[41.51,43.53]	215.93***	.64
	LM	67	25.03 (4.77)	32.27 (5.62)	32.03	.47	[31.11,32.96]		

Note: Quade's rank ANCOVA was conducted on ranked residuals with pretest scores as covariates.
Adjusted means (M_{adj}) represent estimated marginal means from the covariate- model.
Effect sizes (ηp^2) are interpreted as approximate due to the rank- nature of the procedure.
*** $p < .001$.

Effect of DI on high- and low-achieving students' interest, cognitive engagement, and achievement in Chemistry

The results of the effect of DI on high- and low-achieving students' interest, cognitive engagement, and achievement in Chemistry are presented in Table 2. Based on Table 2, the adjusted mean interest score of the effect of DI on both high (M_{adj} = 100.49, *SE* = .97) and low-achieving (M_{adj} = 103.18, SE = 1.46, F(1,55) = 1.94, p = .169, ηp^2 = .03) Chemistry students did not differ significantly. Hence, DI may support comparable outcomes for both high- and low-achieving students' interest in Chemistry. The partial eta-squared (.03) was also calculated (see Table 2) to assess the magnitude of the effect of DI on the achievement levels. Achievement level accounts for a small effect size of approximately 3% variation in students' interest in Chemistry.

The results in Table 2 show that the adjusted mean cognitive engagement score on both high (M_{adj} = 58.63, SE = .79) and low-achieving (M_{adj} = 57.16, SE = 1.19, F(1,55) = .56, p = .456, ηp^2 = .01) Chemistry students, when taught Chemistry using DI, was not statistically significant. This suggests that the cognitive engagement of high- and low-achieving students was similar after the intervention using DI. Achievement level accounts for a small effect size, approximately 1% of the variation in students' cognitive engagement in Chemistry, as indicated by the partial eta-square of .01.

Furthermore, Table 2 reveals the adjusted mean achievement score of the effect of DI on both high (M_{adj} = 42.13, SE = .51) and low-achieving (M_{adj} = 42.48, SE = .77, F(1,55) = 1.15, p = .289, ηp^2 = .02) Chemistry students did not differ significantly. This suggests that DI was associated with comparable levels of achievement across achievement groups. The partial eta-square value of .02 indicates a small effect size and that achievement level accounts for approximately 2% of the variance in students' achievement in Chemistry when taught using DI. The similarity of effect sizes across groups may indicate that high-achieving students approached the upper limit of the posttest scale, thereby limiting the sensitivity of the measure to capture further gains.

Table 2

Quade's rank ANCOVA for the effect of differential instruction on high- and low- students' outcomes

Variable	AL	*n*	Pretest *M (SD)*	Posttest *M (SD)*	M_{adj}	*SE*	95% *CI*	$F(1,122)^{\dagger}$	ηp^2
Interest	High	38	71.76 (7.69)	100.32 (5.28)	100.49	.97	[98.55,102.43]	1.94	.03
	Low	19	61.00 (7.74)	103.53 (6.01)	103.18	1.46	[100.26,106.10]		
Cog. Eng.	High	38	46.47 (6.16)	60.89 (5.60)	58.63	.79	[57.05,60.21]	.56	.01
	Low	19	37.84 (6.13)	52.63 (8.28)	57.16	1.19	[54.78,59.53]		
Achievement	High	38	25.92 (3.80)	42.53 (3.36)	42.13	.51	[41.10,43.15]	1.15	.02
	Low	19	20.47 (4.01)	41.68 (2.21)	42.48	.77	[40.94,44.02]		

† No value of F was statistically significant for $p < .05$.

AL = Achievement level.

Discussion

The results of the study revealed that DI was significantly associated with higher levels of students' interest in Chemistry than the lecture group. The treatment showed a large effect size, accounting for 74% of the variation in students' interest, suggesting that the instructional strategy explained a significant proportion of the variance in students' interest. Moreover, the analysis on the effect of DI on high- and low-achieving students' interest in Chemistry revealed that both groups experienced increased interest. Therefore, compared with the lecture method, DI can serve as a fulcrum for improving students' interest, regardless of their achievement level. This is realised when learning tasks are perceived as relevant, support personalised learning, and are likely to connect Chemistry content with students' readiness levels. The findings align with those of the previous studies (Suson et al., 2020; Abdel qader, 2019) on the effectiveness of DI and personalised strategy on students' interest. It is also in line with Neuvirthova and Gadusova (2021), who highlighted the need to adapt teaching methods to cater to individual students' strengths, learning needs and interests. Yusnidar et al. (2024) further reported that DI is an instructional strategy that helps teachers prepare and deliver lessons while utilising and modifying a variety of strategies to maximise students' interests, requirements, and skills.

The study's results showed that students instructed with DI had an increased adjusted mean cognitive engagement score in contrast to the LM group. The hypothesis analysis further showed a statistically significant association between DI and students' cognitive engagement in Chemistry. The treatment accounted for a large effect size, explaining 54% of the variation in students' cognitive engagement. In addition, the analysis of the effect of DI on high- and low-achieving students' cognitive engagement in Chemistry revealed that both groups' cognitive engagement was enhanced. Consequently, compared with the lecture method, DI optimises students' cognitive engagement regardless of their achievement level. Although the association between DI and cognitive engagement was established, the mechanism underlying it was not determined due to the absence of process- measures or pathways. Hence, it suggests that DI provides varied tasks and assignments, a variety of instructional strategies, and personalised learning for students. These findings echo earlier studies by Saputri et al. (2023) and Lavania and Nor (2020), which report links between DI usage and improved students' cognitive processing and cognitive engagement. Suson et al. (2020) noted that DI could influence students' readiness to learn, given its variety and learning processes, thereby fostering the highest levels of engagement and achievement. This implies that DI could suit the needs of high-achieving students as well as the desires, interests, and difficulties of low-achieving students.

Furthermore, the study's findings indicated that students in the experimental group outperformed those in the control group in terms of the adjusted mean achievement scores. Tests of the matching hypothesis revealed a significant association between instructional strategy and students' chemistry achievement, favouring those taught using DI. DI also accounted for a large effect size, with 64% of the variation in students' achievement in Chemistry. When comparing the performance of high- and low-achieving students taught Chemistry using DI, the results revealed no significant difference between the two achievement levels. This suggests that DI may promote comparable achievement outcomes across achievement groups. The researchers, therefore, are of the view that this is due to DI's ability to meet the needs and diversities of students by providing challenging tasks for high-achieving students and providing support for low-achieving students. Hence, both groups are carried along by the teachers and their peers. Taken together, the intervention's effect sizes on interest, cognitive engagement, and achievement were notably large; they align with recent literature (Am et al., 2023; Hu, 2024) but exceed Cohen's (1988) conventional benchmarks. Therefore, rather than the instructional strategy alone, the effect sizes of this magnitude may be partly due to contextual and methodological factors, such as the potential novelty effect, the relatively short intervention duration, the quasi-experimental design, and the imbalanced sample sizes. These findings are consistent with previous studies (Özüdoğru, 2022; Al-Shehri, 2020) that highlighted the efficacy of DI in improving students' achievement. Similarly, the finding is consistent with Magableh and Abdullah (2020), who highlighted the significant impact of DI on the achievement of grade 8 English language students in Jordan. Moreover, studies involving meta-analysis and systematic reviews on DI, while acknowledging variations of its effectiveness across countries, subjects, and educational levels, reported a moderate to large effect size ranging from +.509 to +.741 on students' learning outcomes, cognitive skills, and critical thinking (Hu, 2024; Smale-Jacobse et al., 2019). This could be due to differences in teachers' characteristics and the expectancy effect.

The results of this study align with Vygotsky's Sociocultural Theory, particularly the Zone of Proximal Development (ZPD), which supports differentiated instruction by emphasising tailored support based on students' developmental levels (Vygotsky, 1978). For low-achieving students, teachers can provide scaffolding such as guided practice, simplified tasks, and peer support to help them grasp chemistry concepts within their ZPD. For high-achieving students, more complex tasks or assignments, leadership roles, and independent projects can extend their learning beyond current capabilities. This approach enhances meaningful engagement and interest and improves achievement by ensuring that all students are appropriately challenged and supported, making Vygotsky's theory a strong foundation for differentiated instruction in diverse chemistry classrooms.

The study's findings showed that DI is significantly associated with improved interest, cognitive engagement, and achievement among both high- and low-achieving students in Chemistry. This suggests that DI is highly promising for supporting students in similar educational contexts. The sustainability of implementing DI in the Nigerian secondary school context requires careful consideration, given large class sizes and inadequate instructional resources. However, its effective implementation may be feasible if teachers adapt to local realities, such as flexible grouping, structured peer-assisted learning, and simplified tiered assignments. Moreover, DI sustainability can be strengthened by policymakers through the provision of instructional materials, professional development, and collaborative opportunities for both teachers and students. This implies that educational stakeholders and policymakers may consider using context-specific implementation through teacher training, iterative feedback and situational analysis to broaden the applicability of DI in chemistry and other school subjects.

Despite these benefits, this study is limited in that it was conducted using four schools in an educational zone in Anambra State, Nigeria. Consequently, the study's findings may have limited applicability in other secondary schools. Additionally, differences in sample sizes between the comparison groups could limit statistical power. Specifically, the lack of significant differences between these groups might have been influenced by reduced statistical power in the smaller sub-sample, rather than indicating a true absence of effect. Furthermore, it is possible that the high achievers reached the upper limit of the Chemistry Achievement Test (CAT) scale, suggesting a ceiling effect that may have limited their ability to detect further gains. Therefore, future studies could employ more sensitive or tiered assessment tools, such as multi-level test items, diagnostic two-tier/three-tier instruments, rubric-based extended-response questions, adaptive testing, and performance-based tasks, which allow for the differentiation of learner abilities and are more effective in capturing gains among advanced learners. The assumptions of ANCOVA were violated, and the study utilised a quasi-experimental design, which does not allow for randomisation of the samples. Although these were controlled using Quade's ANCOVA to account for pre-existing differences, unobserved variables such as teachers' interest and other classroom factors may have affected the outcomes of the study. Also, expectancy bias may have been introduced, as teachers may have been aware of the objectives of the study. The intervention duration limits the study, as a four-week intervention may yield inflated effect sizes due to the strategy's novelty effect. Therefore, the researchers recommend that future studies should use a longer duration to determine whether these effects are maintained over time. The researchers acknowledged their inability to perform a construct validation on the two internationally adapted instruments (CIS and CCES). However, the instruments underwent face and content validation, as well as cultural and contextual adaptations, and were deemed sufficient for use in this study. This quantitative study was limited to data on interest, cognitive styles, and achievement; however, future studies can incorporate other variables, such as retention, students' socio-economic status, and critical thinking, using a mixed-methods design, which provides in-depth insight into these variables. A longitudinal study can be carried out using the study variables, in which students' attitudes, challenges, and perceptions regarding the implementation of DI can be explored.

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