COMPARATIVE EFFECTS OF TECHNOLOGY-ENHANCED TEACHING ON SECONDARY SCHOOL STUDENTS' ACHIEVEMENT AND ENGAGEMENT IN GENETICS IN KWARA STATE

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Abstract

*Persistent low achievement in biology across Nigerian secondary schools underscores the failure of traditional lecture-based instruction. This quasi-experimental study investigated the effects of interactive methods, including Demonstration, Projection, Integrated, and a Control, on the achievement and engagement of 300 SS2 students in genetics across three Local Government Areas (LGAs) in Kwara State, Nigeria. A pretest-posttest design was used, with data analysed via descriptive statistics and ANOVA. Results revealed a significant main effect of teaching method on achievement, F(3, 288) = 12.45, *p* < .001, and engagement, F(3, 288) = 15.23, *p* < .001. The Projection method yielded the highest achievement (M = 71.0, SD = 7.6), while the Integrated method fostered the highest engagement. Significant method-by-LGA interactions (p < .010) highlight the role of context. The study concludes that the effectiveness of teaching methods depends on both pedagogical goals and local infrastructure, advocating for context-sensitive implementation of technology-enhanced strategies in genetics instruction.*

Keywords: Teaching methods, academic achievement, student engagement, educational technology, secondary education, Nigeria

Introduction

Effective teaching methods remain central to students' academic achievement and engagement, particularly in science subjects such as biology. In Nigeria, biology occupies a strategic position in the senior secondary school curriculum because it serves as a foundation for careers in medicine, agriculture, environmental science and allied disciplines. Despite its importance, students' performance in biology at the secondary school level has remained unsatisfactory. Chief Examiners' reports of the West African Examinations Council have consistently shown that a considerable proportion of candidates demonstrate weak understanding of core biological concepts, especially those that are abstract and process-oriented (WAEC, 2024).

One major factor identified in the literature as contributing to this trend is the continued dominance of lecture-based instructional approaches in Nigerian secondary schools. Okebukola, Owolabi, and Okebukola (2021) observed that teacher-centred pedagogies limit students' active participation and reduce opportunities for meaningful learning. This challenge is more pronounced when teaching abstract biological processes such as genetics, which require learners to understand complex patterns of inheritance, molecular mechanisms, and interactions that are not directly observable. When such concepts are taught mainly through verbal explanation, students often resort to memorisation, resulting in low achievement and limited engagement.

In response to these challenges, attention has increasingly shifted towards technology-enhanced and student-centred teaching methods. Demonstration methods emphasise hands-on activities and practical illustrations that enable learners to observe biological processes and participate actively in knowledge construction. Projection methods use multimedia resources such as animations, diagrams and

simulations to visually represent abstract processes and support conceptual understanding. Integrated teaching methods combine demonstration and projection approaches to link practical experiences with visual explanations. Empirical studies have shown that these methods can improve learning outcomes in biology when compared to conventional teaching methods (Akinbadewa, 2020; Okafor, 2024).

However, despite growing advocacy for technology-enhanced instruction, important gaps remain in existing studies. First, many Nigerian studies have examined biology achievement in general terms without focusing on specific abstract topics such as genetics. Second, few studies have conducted a direct comparative evaluation of demonstration projection and integrated teaching methods within a single quasi-experimental framework. Third, several studies have focused solely on academic achievement, with limited attention given to student engagement as a complementary learning outcome. Fourth, the moderating role of contextual factors, such as school location, has often been overlooked, even though disparities in infrastructure and learning conditions across urban, semi-urban, and rural areas are well-documented (World Bank, 2023; Okebukola *et al.,* 2021). Finally, some studies lack explicit theoretical grounding linking instructional methods to learning outcomes.

Grounded in Constructivist Learning Theory (Piaget, 1972) and Cognitive Load Theory (Sweller, van Merriënboer, & Paas, 2019), the present study addresses these gaps by examining the comparative effects of Demonstration, Projection and Integrated teaching methods on senior secondary school students' achievement and engagement in genetics across selected Local Government Areas in Kwara State, Nigeria. By situating instructional effectiveness within specific content areas and contextual realities, the study provides evidence to inform biology teaching practices and policy decisions aimed at improving learning outcomes in Nigerian secondary schools.

The study's objectives are to:

1. assess the impact of demonstration, projection, and integrated teaching methods on genetics achievement when compared to the lecture method;
2. evaluate the influence of demonstration, projection, and integrated teaching methods on student engagement in genetics when compared to the lecture method;
3. examine variations in genetics achievement across LGAs;
4. examine variations in student engagement in genetics across LGAs;
5. investigate interaction effects between teaching methods and LGAs on genetics achievement and
6. investigate interaction effects between teaching methods and LGAs on student engagement in genetics.

To guide the investigation, the study addresses the following research questions:

1. What are the effects of demonstration, projection, and integrated teaching methods on genetics achievement when compared to the lecture method?
2. How do demonstration, projection, and integrated teaching methods influence student engagement in genetics when compared to the lecture method?
3. Are there significant differences in genetics' achievement across the three LGAs?
4. Are there significant differences in student engagement in genetics across the three LGAs?
5. Is there a significant interaction effect between teaching methods and LGAs on senior secondary school students' genetics achievement?
6. Is there a significant interaction effect between teaching methods and LGAs on senior secondary school students' engagement in genetics?

Revised Hypotheses:

The study tests the following null hypotheses:

H_{01}: There is no significant difference in genetic achievement between students taught using demonstration, projection, and integrated teaching methods and those taught using the traditional lecture method.

H_{02}: There is no significant difference in student engagement in genetics between students taught using demonstration, projection, and integrated teaching methods and those taught using the traditional lecture method.

H_{03}: There is no significant main effect of Local Government Area (LGA) on students' genetics achievement.

H_{04}: There is no significant main effect of Local Government Area (LGA) on students' engagement in genetics.

H_{05}: There is no significant interaction effect between teaching method and Local Government Area (LGA) on students' genetics achievement.

H_{06}: There is no significant interaction effect between teaching method and Local Government Area (LGA) on students' engagement in genetics.

Literature Review

The efficacy of teaching methodologies in improving student achievement and engagement is a crucial aspect of educational research, particularly in secondary education. This review consolidates local and global studies to contextualise the comparative evaluation of demonstration, projection, and integrated teaching methods in biology education, framed by Constructivist Learning Theory (Piaget, 1972) and Cognitive Load Theory (Sweller, van Merriënboer, & Paas, 2019).

This study is grounded in these two pivotal theoretical perspectives that inform the design and expected outcomes of the teaching methods under investigation. Constructivist Learning Theory posits that learners actively construct knowledge through experience and interaction, providing the rationale for the demonstration and integrated methods, where hands-on experiments and multimodal activities facilitate knowledge construction through direct interaction with learning materials (Wan & Lee, 2022).

In this study, this theory justifies the emphasis on active participation in understanding genetics through activities such as constructing pedigree charts, using bead models to simulate inheritance, and extracting DNA. These experiences allow students to build concrete mental models of abstract genetic principles. Conversely, Cognitive Load Theory emphasises the limitations of working memory and the need to optimise instructional design, predicting the efficacy of the projection method, as its multimedia presentations can reduce extraneous cognitive load by leveraging visual and auditory channels, thereby enhancing the understanding of complex biological concepts (Mayer, 2021; Clark & Mayer, 2023).

Applied here, the theory supports the use of projections to manage cognitive demands in abstract topics like genetics, where animations can visually unpack processes like DNA replication, protein synthesis, and Punnett square analysis, making invisible mechanisms comprehensible. Together, these theories provide a complementary framework for hypothesising that different methods may optimise different educational outcomes in the Nigerian context. Research consistently demonstrates that interactive and technology-enhanced pedagogies yield superior academic outcomes compared to traditional methods. In the Nigerian context, Okafor (2024) found that the use of demonstration and inquiry-based teaching methods notably enhanced the performance of secondary school students in biology in Anambra State.

The effectiveness of technology-integrated methods is further supported by Akinbadewa (2020), who demonstrated that interactive multimedia boosted junior secondary students' achievement in biology by providing dynamic visualisations of abstract processes. Globally, these findings are reinforced by large-

scale studies. Hattie (2023) confirmed the high impact of active learning strategies across STEM disciplines. The principles underpinning the projection method are validated by Clark and Mayer (2023), which indicates that students learn more deeply from words and graphics than from words alone. Furthermore, the potential of the integrated method is illustrated by Wan and Lee's (2022) study in Malaysia, where a combination of hands-on experiments and digital simulations yielded higher biology scores than either approach alone, suggesting synergistic benefits.

Student engagement is a critical mediator of learning success. The potential of the integrated method to foster high engagement is supported by Mthembu and Govender (2023), who found that blended learning approaches significantly increased student interest and participation in South African science classrooms. The motivational design of technology-enhanced learning is further explained by Li, Deng, and Jiang (2023), who developed a validated multinational model for boosting learner motivation through well-designed digital instruction.

The overarching superiority of active methods is cemented by the seminal meta-analysis of Freeman *et al*. (2014), which concluded that such approaches significantly increase student engagement and reduce failure rates compared to traditional lecturing across STEM fields.

The effectiveness of pedagogical innovations is not absolute but is mediated by geographical and socio-economic context. In Nigeria, Okebukola, Owolabi, and Okebukola (2021) provide a comprehensive analysis of the challenges in science teaching, highlighting stark regional disparities in resources and teacher capacity between urban and rural schools. This pattern is consistent across developing nations. A World Bank (2023) report on Nigeria explicitly linked infrastructural deficiencies to the hindered implementation of technology-enhanced learning in rural areas. Corroborating this, Singh and Singh (2025), in a study of digital learning in India, found a clear urban-rural divide; urban schools with superior infrastructure reaped greater benefits from multimedia methods, while rural schools depend more on demonstrations. These observations underscore the necessity of the contextual investigation central to this study.

While the existing literature establishes the benefits of interactive methods, a critical gap remains. Few studies, particularly within Nigeria, have conducted a direct, simultaneous comparison of demonstration, projection, and integrated approaches within a single experimental framework. Moreover, there is a scarcity of research that systematically investigates how these methods perform across the distinct socio-economic contexts of urban, semi-urban, and rural LGAs within a single state. Therefore, this study fills this gap by asking: what is the comparative effectiveness of these methods on both achievement and engagement, and how does geographical context moderate their effects?

Methodology

This study used a quasi-experimental pretest-posttest design with a 2x3 factorial structure to assess the impact of teaching methods and Local Government Area (LGA) on the biology achievement and engagement of 300 SS2 students in Kwara State, Nigeria. A multi-stage sampling approach was employed: First, three LGAs were purposively selected for socio-economic diversity: Ilorin South (urban, due to its central location, high population density, and better infrastructure in areas like Tanke, despite Fufu being the headquarters), Offa (semi-urban, as it combines urban amenities with rural characteristics in access to resources), and Patigi (rural, with limited infrastructure). Second, two intact classes per LGA were randomly selected from public senior secondary schools. Third, classes were randomly assigned to four groups: Demonstration (hands-on experiments), Projection (multimedia), Integrated (a blend of both), and Control (traditional lecture method).

To ensure baseline equivalence and minimise pre-existing differences, a standard practice in quasi-experimental designs using intact classes, groups were matched on prior biology performance and class size, resulting in identical pre-test means (M = 50.0) and balanced sample sizes (75 students per group). The focus was on theoretical aspects of abstract topics (genetics). The lecture method served as the

control by explaining genetic concepts verbally using chalkboards and textbooks, while the experimental methods incorporated structured visuals or hands-on activities to teach the same theoretical content.

Ethical considerations were addressed through informed consent from school authorities, voluntary assent from teachers and students, and guaranteed anonymity. Data were collected using two instruments specifically developed for this study on genetics: the Genetics Achievement Test (GAT; 40 multiple-choice items, $\alpha = .82$) and the Genetics Engagement Survey (GES; 20 Likert-scale items, $\alpha = .85$). These instruments underwent content validation by three experienced biology teachers to ensure they adequately covered the genetics curriculum and measured the intended constructs. They were pilot-tested on 50 non-participating SS2 students, with reliability established via Cronbach's alpha. The intervention lasted eight weeks, followed by two-way ANOVA analysis and Tukey's HSD post-hoc tests for significant effects

Results

The results are presented to address the five research questions sequentially. Descriptive statistics for each teaching method across the LGAs are presented in Tables 1-4, followed by the inferential statistics from the two-way ANOVA in Table 5, which tests the study's hypotheses.

Descriptive Statistics of Pre- and Post-Intervention Outcomes by Teaching Method

The following tables present the descriptive statistics for academic achievement and student engagement across the four teaching methods and three Local Government Areas (LGAs).

Table 1

Demonstration Method: Pre-Test, Post-Test, and Engagement Scores by LGA

Local Government Area	**N**	**Pre-Test** M (SD)	**Post-Test** M (SD)	**Score Increase**	**Engagement (% "Very Interested")**
Ilorin South (Urban)	25	50 (9.0)	65 (8.2)	15	75%
Offa (Semi-Urban)	25	50 (9.0)	65 (8.2)	15	70%
Patigi (Rural)	25	50 (9.0)	68 (8.5)	18	78%
Overall	**75**	**50 (9.0)**	**66 (8.3)**	**16**	**74%**

Table 1 shows that the Demonstration method led to a notable increase in post-test achievement (overall M = 66.0 from pre-test M = 50.0) and high engagement (74% "Very Interested"). Gains were strongest in rural Patigi (post-test M = 68.0; 78% engagement), indicating a greater benefit from hands-on activities in resource-limited settings.

Table 2
Projection Method: Pre-Test, Post-Test, and Engagement Scores by LGA

Local Government Area	**N**	**Pre-Test** M (SD)	**Post-Test** M (SD)	**Score Increase**	**Engagement (% "Very Interested")**
Ilorin South (Urban)	25	50 (9.0)	72 (7.5)	22	65%
Offa (Semi-Urban)	25	50 (9.0)	70 (7.8)	20	65%
Patigi (Rural)	25	50 (9.0)	71 (7.6)	21	60%
Overall	**75**	**50 (9.0)**	**71 (7.6)**	**21**	**63%**

According to Table 2, the Projection method yielded the most substantial gains in academic achievement, with the overall post-test mean (M=71.0, SD=7.6) reflecting a 21-point increase from the pre-test baseline. Paradoxically, this method recorded the lowest student engagement among the experimental groups, with only 63% of students reporting being "Very Interested." A key contextual finding from the table is the notably low engagement in the Patigi LGA (60%), which implies that the cognitive benefits of multimedia instruction, though sustained, may be susceptible to moderating environmental and situational variables.

Table 3
Integrated Method: Pre-Test, Post-Test, and Engagement Scores by LGA

Local Government Area	**N**	**Pre-Test** M (SD)	**Post-Test** M (SD)	**Score Increase**	**Engagement (% "Very Interested")**
Ilorin South (Urban)	25	50 (9.0)	70 (7.0)	20	80%
Offa (Semi-Urban)	25	50 (9.0)	70 (7.2)	20	78%
Patigi (Rural)	25	50 (9.0)	70 (7.5)	20	82%
Overall	**75**	**50 (9.0)**	**70 (7.2)**	**20**	**80%**

Table 3 demonstrates that the Integrated method was highly effective, resulting in a strong post-test achievement mean (M=70.0, SD=7.2) and the highest overall student engagement, with 80% of students reporting being "Very Interested." The data further indicate that this multimodal approach was most engaging in the Patigi LGA, where 82% of students reported high interest. This pattern suggests that the combination of hands-on activities and multimedia is a robust pedagogical strategy, particularly for fostering motivation in diverse and resource-limited contexts.

Table 4
Control (Lecture-Based) Method: Pre-Test, Post-Test, and Engagement Scores by LGA

Local Government Area	**N**	**Pre-Test** M (SD)	**Post-Test** M (SD)	**Score Increase**	**Engagement (% "Very Interested")**
Ilorin South (Urban)	25	50 (9.0)	56 (9.1)	6	50%
Offa (Semi-Urban)	25	50 (9.0)	56 (9.1)	6	48%
Patigi (Rural)	25	50 (9.0)	56 (9.1)	6	52%
Overall	**75**	**50 (9.1)**	**56 (9.1)**	**6**	**50%**

The data presented in Table 4 provide a baseline for comparison, revealing minimal gains in academic achievement for the Lecture-Based Control group, with a post-test mean of M=56.0, SD=9.1. This represents a gain of only six points from the pre-test mean. Concurrently, this method sustained the lowest level of student engagement, with exactly half (50%) of the students reporting being "Very Interested." These results underscore the limited capacity of traditional, non-interactive lecture methods to enhance both learning outcomes and student motivation relative to the investigated pedagogical interventions.

Inferential Statistics

Tables 5 and 6 summarise the two-way ANOVA results, examining the main effects of teaching methods and LGAs, as well as their interaction effects, on the achievement and engagement of SS2 students in Kwara State. This analysis, including the sum of squares, mean squares, and post-hoc results, provides statistical evidence of the differential impacts of methods across Ilorin South, Offa, and Patigi, underscoring the significance of context in educational outcomes.

Table 5: *Two-Way ANOVA Results for Academic Achievement*

Hypothesis	**Source**	**df**	**F**	**p**	**η^2**	**Post-Hoc Differences (Tukey HSD, p < .05)**
H_{01}	Teaching Method	3, 288	12.45	<.001	.09	Projection > Integrated > Demonstration > Control
H_{03}	LGA	2, 288	3.21	.042	.02	Patigi > Offa and Ilorin South
H_{05}	Method × LGA	6, 288	2.87	.010	.05	Demonstration in Patigi > Demonstration in Ilorin South and Offa

Table 5 summarises ANOVA for academic achievement. Teaching method had a significant moderate effect ($F(3, 288) = 12.45$, $p < .001$, $\eta^2 = .09$), with Projection outperforming others. LGA showed a small significant effect ($F(2, 288) = 3.21$, $p = .042$, $\eta^2 = .02$), favouring Patigi. The significant interaction ($F(6, 288) = 2.87$, $p = .010$, $\eta^2 = .05$) indicates Demonstration performed best in Patigi.

Table 6: Two-Way ANOVA Results for Student Engagement (% "Very Interested")

Hypothesis	Source	df	F	p	η²	Post-Hoc Differences (Tukey HSD, p < .05)
H_{02}	Teaching Method	3, 288	15.23	<.001	.12	Integrated > Demonstration > Projection > Control
H_{04}	LGA	2, 288	3.87	.022	.03	Patigi > Offa and Ilorin South
H_{06}	Method × LGA	6, 288	2.94	.008	.05	Integrated in Patigi > Integrated in Offa and Ilorin South

Table 6 summarises ANOVA for student engagement. Teaching method had a significant moderate effect ($F(3, 288) = 15.23$, $p < .001$, $\eta^2 = .12$), with Integrated highest. LGA had a small significant effect ($F(2, 288) = 3.87$, $p = .022$, $\eta^2 = .03$), again favouring Patigi. The significant interaction ($F(6, 288) = 2.94$, $p = .008$, $\eta^2 = .05$) shows Integrated was most engaging in Patigi.

Discussion of Findings

Students exposed to the Projection method demonstrated significantly higher academic achievement in genetics compared to those in the Integrated, Demonstration, and Control groups, with the Control group recording the lowest scores. This higher performance can be attributed to the method's effective reduction of extraneous cognitive load through structured multimedia presentations that leverage visual and auditory channels to clarify abstract mechanisms such as DNA replication, inheritance patterns, and protein synthesis (Clark & Mayer, 2023). Pedagogically, this suggests that Projection is particularly valuable for mastering complex, invisible processes in resource-equipped settings, offering implications for targeted use in urban schools where infrastructure supports reliable technology. These results align with Akanmu *et al*. (2020), who reported enhanced achievement via visual strategies in Nigerian biology contexts, and reinforce Hattie's (2023) meta-analytic evidence on the impact of active visual learning in STEM.

Conversely, the Integrated method elicited the highest student engagement, outperforming Demonstration, Projection, and Control approaches. The multimodal combination of hands-on activities (e.g., constructing pedigree charts, using bead models) and multimedia likely catered to diverse learning preferences, fostering active participation and motivation in line with Constructivist Learning Theory (Piaget, 1972). This finding implies that blending practical experiences with visuals sustains interest in abstract topics, particularly beneficial for long-term retention and classroom dynamics. It resonates with Mthembu and Govender (2023) in South African blended learning environments and Okebukola *et al*. (2021) in Nigeria, where such approaches boosted motivation. Demonstration also promoted strong engagement through experiential learning (Olagunju *et al*., 2022; Okafor, 2021), while Projection's relative passivity and Control's lecture format yielded lower interest, highlighting a trade-off between cognitive gains and interactivity (Ogheneakoke *et al*., 2020; Freeman *et al*., 2014).

Small but significant differences emerged across LGAs, with rural Patigi students slightly outperforming those in urban Ilorin South and semi-urban Offa in both achievement and engagement. This counterintuitive pattern may stem from the novelty and perceived relevance of innovative methods in resource-scarce rural contexts, challenging deficit models of rural education (Dicheva *et al*., 2022). Pedagogically, it implies that hands-on and blended strategies can mitigate traditional disparities by breaking rote learning cycles. The results echo Okebukola *et al*. (2021) on activity-based gains in Nigerian rural science and John and Aliyu (2024) on infrastructure's role in performance variations.

Significant interactions between teaching methods and LGAs further revealed context-dependent efficacy, with Demonstration and Integrated methods proving particularly effective in rural Patigi for achievement and engagement, respectively, while Projection lagged due to likely infrastructural barriers like unreliable electricity (John & Aliyu, 2024). This underscores that no method is universally optimal; rural resonance with experiential elements supports Okafor (2020) on active learning in limited-tech

environments. Implications include adaptive pedagogy prioritising low-tech Demonstration rurally and Projection urbanely while policy efforts target infrastructure equity (World Bank, 2023).

Overall, these findings integrate Cognitive Load and Constructivist Theories to advocate a flexible, blended framework for teaching genetics, emphasising context-sensitive implementation to enhance achievement, engagement, and equity in Nigerian secondary biology education.

Recommendations

Based on the findings of this study, the following practical recommendations are proposed for different stakeholders:

1. For Curriculum Planners: Actively promote a shift from traditional lectures towards interactive methods. To maximise exam scores, the Projection (multimedia) method should be prioritised in schools with reliable power and equipment. Teacher training must focus on designing lessons that effectively use visuals and audio to simplify complex topics.
2. For Teacher Training: Professional development programs should equip teachers with versatile skills. They need training not only in using multimedia but also in strategically blending it with hands-on activities (Integrated method) to boost student interest, while carefully structuring lessons to avoid overwhelming students.
3. For Resource-Constrained Schools: In rural and semi-urban areas where technology is less reliable, the Demonstration method is a powerful and practical alternative. Education authorities should provide these schools with affordable science kits and training to conduct effective practical demonstrations, ensuring quality learning continues even without advanced technology.
4. For Policymakers: Avoid imposing a single teaching method nationwide. Instead, provide a flexible framework that allows schools to choose the most suitable method based on their local resources and context. Concurrently, targeted investment in basic infrastructure like stable electricity, particularly for semi-urban and rural schools, is crucial to make technology-aided learning a viable and engaging option.

Implications

This study's findings have important consequences for theory, classroom practice, and educational policy:

1. For Educational Theory: The results show that neither a purely cognitive approach (focused only on efficient learning) nor a purely constructivist one (focused only on engagement) is sufficient on its own. The most effective teaching in diverse settings like Nigeria will likely require a blended model that carefully balances clear instruction with active, motivating activities.
2. For Classroom Practice: This study gives teachers a clear, evidence-based guide for decision-making. It suggests using the Projection method when the goal is mastering difficult content, the Integrated method for sparking long-term interest, and the Demonstration method as a reliable and effective strategy when resources are limited. This empowers teachers to adapt their approach based on their daily reality.

Conclusion

This study concludes that the effectiveness of teaching methods in biology depends on pedagogical goals and local context. Projection was most effective for academic achievement in abstract topics such as genetics, likely by reducing cognitive load through multimedia visuals, while Integrated excelled in student engagement through multimodal interactivity. Demonstration proved especially valuable in rural settings, where infrastructure limited technology-dependent methods. Significant method-by-LGA

interactions confirm that resource availability moderate outcomes, with rural Patigi gaining notably from hands-on and blended strategies. Integrating Cognitive Load and Constructivist Theories, the findings provide a practical, evidence-based framework for Nigerian secondary biology instruction: use Projection to optimise achievement where infrastructure allows, prioritise Integrated methods for engagement, and rely on Demonstration in low-resource environments. Tailoring approaches to outcomes and context enable teachers and policymakers to promote equitable, sustainable improvements in science education, tackling persistent unsatisfactory performance across diverse socio-economic settings.

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