

Impact of Phet Simulation Instructional Strategy on Students' Interest and Achievement in Biology in Senior Secondary Schools in the FCT, Abuja, Nigeria

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Abstract

This study investigated the impact of Physics Education Technology (PhET) simulation instructional strategy on senior secondary school students' interest and achievement in Biology in the Federal Capital Territory (FCT), Abuja, Nigeria. The study adopted a quasi-experimental research design and was guided by four research questions and four null hypotheses. The population comprised 14,891 Biology students in public senior secondary schools in the FCT. A sample of 123 Senior Secondary School II students drawn from two intact classes participated in the study. The experimental group consisted of 65 students, while the control group comprised 58 students. Data were collected using the Biology Interest Assessment Scale (BIAS) and Biology Achievement Test (BAT). The instruments yielded reliability coefficients of 0.79 and 0.83 respectively. The experimental group was taught selected Biology concepts using PhET simulations, while the control group received instruction through the conventional teaching method for six weeks. Mean and standard deviation were used to answer the research questions, while independent-samples t-test was used to test the hypotheses at the 0.05 level of significance. Results showed that students taught using PhET simulations recorded higher interest ($M = 46.98$, $SD = 4.84$) than the control group ($M = 35.57$, $SD = 5.19$), and higher achievement ($M = 75.71$, $SD = 3.13$) than the control group ($M = 58.71$, $SD = 4.25$). The differences were statistically significant. However, no significant gender differences were found in interest or achievement among students exposed to PhET simulations. The study concluded that PhET simulation is an effective and gender-inclusive instructional strategy for improving students' interest and achievement in Biology. It was recommended that PhET simulations be integrated into Biology instruction and that teachers be provided with appropriate training and technological resources.

Keywords: PhET simulation, Biology education, students' interest, academic achievement, gender, secondary schools

Introduction

Biology occupies an important position in science education because it provides learners with knowledge of living organisms, life processes, ecosystems, health, agriculture, biotechnology and environmental sustainability. At the senior secondary school level, Biology provides a foundation for further education and careers in medicine, agriculture, environmental science, biotechnology

and other science-related disciplines. Effective Biology education is therefore important not only for students' academic development but also for scientific literacy and national development. Despite the importance of Biology, students' achievement and interest in the subject remain areas of concern. Poor achievement has been associated with several factors, including ineffective instructional approaches, inadequate instructional resources and excessive reliance on teacher-centred methods. Ibe and Abamuche (2019) observed that instructional approaches have considerable implications for students' achievement and interest in secondary school Biology. Similarly, Orakwue and Okigbo (2023) drew attention to factors associated with students' achievement in Biology. Conventional teaching approaches often position the teacher as the principal source of knowledge while students receive information with limited opportunities to manipulate variables, visualize complex processes or undertake meaningful investigations. Such approaches may be inadequate for concepts involving microscopic, dynamic or abstract processes. Biology topics such as photosynthesis, cellular structures and physiological processes require learners to establish relationships among structures, functions and processes that may be difficult to observe directly. Advances in educational technology have created opportunities for the use of interactive simulations to complement classroom instruction. One prominent technological resource is Physics Education Technology (PhET) simulation. Although originally associated with Physics education, PhET simulations have increasingly been applied across science disciplines. The simulations provide interactive environments in which learners manipulate variables, observe outcomes and explore scientific relationships in visual and dynamic forms. PhET simulations can facilitate active learning by transforming abstract scientific ideas into representations with which students can interact. Banda and Nzabahimana (2023) argued that integrating PhET simulations can enhance conceptual understanding by providing learners with opportunities to engage actively with scientific concepts. PhET simulations also provide immediate feedback and enable students to repeat activities without the limitations that may accompany conventional laboratory activities. Cetinkaya and Kirilmazkaya (2022) similarly reported positive outcomes associated with simulation-supported science instruction. The potential influence of simulation is not restricted to cognitive achievement. Interest is an important affective component of learning because students who find a subject engaging are more likely to participate, persist with learning activities and devote cognitive effort to understanding difficult concepts. Harackiewicz, Smith and Priniski (2016) emphasized the importance of interest in supporting learning and educational development. Interactive simulations may stimulate interest by allowing learners to explore concepts rather than merely listen to explanations. The theoretical basis of the present study was informed by Dual Coding Theory and the Cognitive Theory of Multimedia Learning. These perspectives suggest that learning can be strengthened when verbal information is appropriately combined with visual representations. PhET simulations provide animations, diagrams, labels and interactive visual representations which may enable learners to organize scientific information and integrate it with existing knowledge. Consequently, their multimedia characteristics have the potential to promote both engagement and conceptual understanding. Empirical findings concerning PhET simulations generally suggest positive learning outcomes. Okolo and Oluwasegun (2020) found that computer simulation improved achievement and interest in cell division among secondary school students in Abuja. Najib, Yaacob and Md-Ali (2022) similarly reported improved Physics achievement following exposure to PhET interactive simulation activities. Tuyizere and Rutegwa (2024) found favourable effects of PhET-supported instruction on students' conceptual understanding and attitudes toward protein synthesis. However, findings have not been completely consistent. Yunzal and Casinillo (2020), for example, reported results that differed from studies demonstrating strong

effects of PhET-supported instruction. Another issue requiring consideration is gender. Educational technologies should produce learning opportunities that are equitable for male and female students. Some studies have found minimal gender differences in simulation-supported environments, whereas others have suggested possible gender variations. Establishing whether PhET-supported Biology instruction benefits male and female students comparably is therefore important. Although simulation-based learning has received increasing research attention, limited empirical evidence exists concerning the combined influence of PhET simulations on interest and academic achievement in Biology among senior secondary school students in the FCT, Abuja. This study addressed this gap by examining the impact of PhET simulation instructional strategy on students' interest and achievement and by determining whether the outcomes differed according to gender.

Purpose of the Study

The study investigated the impact of PhET simulation instructional strategy on students' interest and achievement in Biology in senior secondary schools in the FCT, Abuja. Specifically, it sought to:

1. determine the difference in interest between students taught Biology using PhET simulation and those taught using the conventional method;
2. determine the difference in achievement between students taught Biology using PhET simulation and those taught using the conventional method;
3. determine whether male and female students taught Biology using PhET simulation differ in interest; and
4. determine whether male and female students taught Biology using PhET simulation differ in achievement.

Research Questions

1. What difference exists between the mean interest scores of students taught Biology using PhET simulation and those taught using the conventional method?
2. What difference exists between the mean achievement scores of students taught Biology using PhET simulation and those taught using the conventional method?
3. What difference exists between the mean interest scores of male and female students taught Biology using PhET simulation?
4. What difference exists between the mean achievement scores of male and female students taught Biology using PhET simulation?

Hypotheses

H01: There is no significant difference between the mean interest scores of students taught Biology using PhET simulation and those taught using the conventional method.

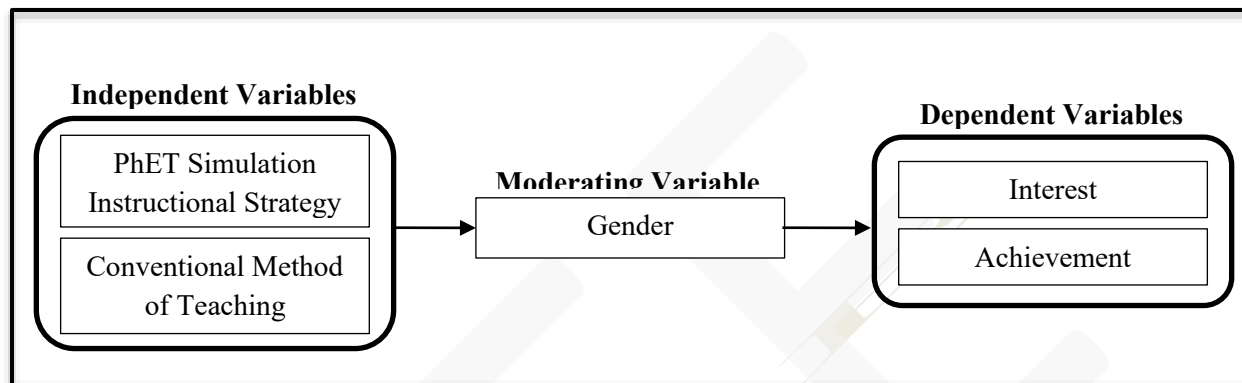
H02: There is no significant difference between the mean achievement scores of students taught Biology using PhET simulation and those taught using the conventional method.

H03: There is no significant difference between the mean interest scores of male and female students taught Biology using PhET simulation.

H04: There is no significant difference between the mean achievement scores of male and female students taught Biology using PhET simulation.

Conceptual Framework

The conceptual framework of the study explains the relationship among the instructional strategy, students' learning outcomes and gender. The independent variable consists of the instructional approaches used for teaching Biology: PhET simulation instructional strategy for the experimental group and the conventional teaching method for the control group. The dependent variables are students' interest and academic achievement in Biology, while gender serves as a moderating variable. The framework assumes that the instructional approach adopted can influence students' interest and achievement, while also allowing the study to determine whether the outcomes of PhET-supported instruction vary between male and female students.



Conceptual Review

Concept of PhET Simulation

Physics Education Technology (PhET) simulations are interactive computer-based learning resources developed to support the teaching and learning of science and mathematics through visualization, manipulation and virtual experimentation. Although the platform originated within Physics education, its simulations and related interactive principles have been applied across science subjects, including Biology. PhET environments typically enable learners to change variables, observe outcomes in real time and explore cause-and-effect relationships in a safe and repeatable setting. Important characteristics of PhET simulations include interactivity, dynamic visual representations, immediate feedback, learner exploration, user-friendly interfaces and support for inquiry-based learning. These characteristics can make abstract or microscopic processes more concrete, permit repeated exploration without the cost and safety limitations of physical laboratory work, and provide opportunities for active learning. However, effective classroom use may be constrained by inadequate ICT facilities, poor electricity supply, limited teacher preparation, insufficient curriculum integration and unequal access to devices or internet connectivity.

Students' Interest in Biology

Interest refers to the tendency to direct attention, curiosity and positive engagement toward an activity, object or subject. In education, interest includes both temporary situational engagement and more enduring individual preference for a field of study. Students who are interested in Biology are more likely to attend to lessons, participate in learning activities, persist with difficult tasks and engage with the subject beyond examination requirements. Interactive simulations can support interest by making lessons more participatory, visually engaging and less abstract. When students manipulate representations and receive immediate feedback, Biology may become more

relatable and enjoyable. Consequently, interest is treated in this study as an important affective learning outcome that may be influenced by the instructional strategy used by the teacher.

Academic Achievement in Biology

Academic achievement refers to the level of knowledge and skills acquired by learners as demonstrated through tests, examinations or other formal assessments. In Biology, achievement reflects students' mastery and application of biological concepts after instruction. It is commonly used to determine the extent to which learning objectives have been attained and to evaluate the effectiveness of teaching strategies. Achievement may improve when learners are actively involved in constructing meaning from instructional experiences. PhET simulations may support this process by enabling learners to connect verbal explanations with dynamic visual models, test ideas and observe patterns that might otherwise remain abstract. In the present study, academic achievement was measured using the Biology Achievement Test covering selected SS II Biology concepts.

Gender as a Moderating Variable

Gender is frequently examined in science education research because differences in access, participation, confidence and learning opportunities may influence educational outcomes. In this study, gender was treated as a moderating variable to determine whether male and female students exposed to PhET simulation differed in their interest and achievement in Biology. Examining gender is important for establishing whether the strategy provides equitable learning opportunities and whether its benefits are comparable across male and female learners.

Empirical Review

Empirical studies on PhET and related computer simulations have generally reported positive effects on students' engagement, conceptual understanding and achievement, although the magnitude of the effects varies across subjects and educational settings. Omar (2019) investigated PhET interactive simulation activities among Grade 9 students in the Philippines using a quasi-experimental design and reported a significant positive influence on students' performance in Physics. Similarly, Özcan, Çetin and Koştur (2020) examined PhET simulation-based instruction on the greenhouse effect among sixth-grade students in Turkey and found a statistically significant achievement advantage for students in the experimental group. Within the Nigerian context, Okolo and Oluwasegun (2020) examined computer simulation in the teaching of cell division among secondary school students in Abuja. Their findings indicated that computer simulation was more effective than the conventional method for improving achievement and interest, while gender was not a determining factor in students' interest. This study is particularly relevant because it was conducted in Abuja and examined both affective and cognitive outcomes, although it focused on a specific Biology concept and used a smaller sample than the present study. Yunzal and Casinillo (2020) assessed the effect of PhET simulations on STEM students' performance in Physics in the Philippines. Unlike several studies reporting significant advantages, their results indicated an insignificant impact on students' performance. This contrasting finding suggests that the effectiveness of simulations may depend on factors such as the instructional design, duration of exposure, subject content, teacher support and characteristics of the learning environment. Najib, Yaacob and Md-Ali (2022) investigated PhET interactive simulation activities among secondary school Physics students in Malaysia and reported significant improvement in achievement for students exposed to the simulation-supported approach. Cetinkaya and Kirilmazkaya (2022) also

reported positive effects of PhET-supported instruction on science attitudes and success among students learning about the greenhouse effect in Turkey. Liwhuliwhue, Ofoegbu and Asogwa (2023) examined PhET virtual laboratory experiments in practical Physics in Ogoja Education Zone, Cross River State, Nigeria. The study found a significant positive effect on students' academic performance and reported no significant gender difference. The gender-neutral result provides empirical support for examining whether similar patterns occur in Biology. Tuyizere and Rutegwa (2024) investigated PhET-supported instruction in Biology among secondary school students in Kigali, Rwanda, with specific attention to protein synthesis. Students exposed to the simulation-supported approach demonstrated higher conceptual understanding and more positive attitudes than those in the comparison group. The study provides direct evidence that PhET-supported learning can be useful in Biology rather than only in Physics or general science. Pranata (2024) examined PhET simulations as game-based learning tools among junior high school students in Indonesia and reported improvements in interest, understanding and motivation. Eleo and Manguilimotan (2024) similarly found PhET interactive simulations to be more effective than conventional instruction for enhancing students' performance in Physics. These findings reinforce the growing evidence that interactive simulations can support both cognitive and affective learning outcomes.

Research Gap

The reviewed studies demonstrate growing evidence for the usefulness of PhET and computer simulations, but important gaps remain. Many previous studies concentrated on Physics or specific science concepts, were conducted outside Nigeria, or examined either achievement or attitude/interest rather than the combined outcomes of interest and achievement. Although some Nigerian studies have investigated computer simulation in Biology, limited empirical evidence exists on the use of PhET simulation specifically for senior secondary school Biology in the FCT, Abuja. In addition, the combined examination of students' interest, achievement and gender within the same study remains limited. The present study addressed these contextual, subject-area and outcome gaps by examining the impact of PhET simulation on students' interest and achievement in Biology and determining whether the effects differ by gender.

Methodology

The study adopted a quasi-experimental research design. The design was appropriate because intact classes were used and complete random assignment of individual students to experimental conditions was not undertaken. Two groups were involved: an experimental group taught using PhET simulation instructional strategy and a control group taught using the conventional instructional method. Both groups were assessed before and after the instructional intervention. The approach enabled comparison of students exposed to PhET simulation with those receiving conventional Biology instruction. The population of the study consisted of 14,891 Biology students in public senior secondary schools in the Federal Capital Territory, Abuja. The sample consisted of 123 Senior Secondary School II students selected from two intact classes. The experimental group comprised 65 students—33 males and 32 females—while the control group comprised 58 students—26 males and 32 females. Two Area Councils, Gwagwalada and Bwari, were involved in the study. Simple random sampling was used in selecting the participating Area Councils and schools. SS II students were selected because they were sufficiently established within the senior secondary school system, while SS III students were preparing for external examinations. The Biology Interest Assessment Scale (BIAS) measured students' interest in

Biology. It contained 15 items structured on a four-point Likert scale comprising Strongly Agree, Agree, Disagree and Strongly Disagree, scored 4, 3, 2 and 1 respectively. The Biology Achievement Test (BAT) consisted of 30 multiple-choice items, each having four response options. The test covered selected SS II Biology concepts, including photosynthesis, digestive system, animal cell and plant cell. The items were prepared to assess students' achievement in the selected Biology concepts following exposure to the respective instructional approaches.

The BIAS and BAT were subjected to face validation by the research supervisors and Biology Education experts in the Department of Science and Environmental Education, Faculty of Education, University of Abuja. The validation process considered clarity, relevance and appropriateness of the items. Recommendations made by the validators were incorporated into the final instruments. A pilot study involving 20 senior secondary school students in Abuja Municipal Area Council, who were not included in the main study, was conducted. Cronbach's alpha was used to determine the internal consistency of the BIAS, yielding a reliability coefficient of 0.79. The Kuder-Richardson Formula 21 was used for the BAT and produced a reliability coefficient of 0.83. These values indicated satisfactory reliability. Mean and standard deviation were used to answer the research questions. Independent-samples t-test was used to test the four null hypotheses at the 0.05 level of significance. A null hypothesis was rejected where the reported probability value was at or below 0.05 and retained where the probability value exceeded 0.05.

Results

Effect of PhET Simulation on Students' Interest and Achievement

Table 1. Interest and Achievement Scores of Experimental and Control Groups

Variable	Group	N	Mean	SD	Mean Difference	t	df	p	Decision
Interest	Experimental	65	46.98	4.84	11.41	12.62	121	0.001	Significant
	Control	58	35.57	5.19					
Achievement	Experimental	65	75.71	3.13	17.00	25.43	121	0.001	Significant
	Control	58	58.71	4.25					

Table 1 shows that students exposed to PhET simulation obtained a mean interest score of 46.98 (SD = 4.84) compared with 35.57 (SD = 5.19) for the conventional-method group. The mean difference of 11.41 favoured the experimental group. The independent-samples t-test showed a statistically significant difference in students' interest, $t(121) = 12.62$, with the probability value reported as 0.00, which was below the 0.05 significance level. Consequently, H_{01} was rejected. This indicates that exposure to PhET simulation was associated with significantly higher interest in Biology. For academic achievement, the experimental group recorded a mean score of 75.71 (SD = 3.13) compared with 58.71 (SD = 4.25) for the control group, producing a mean difference of 17.00. The difference was statistically significant, $t(121) = 25.43$, with the reported probability value below the 0.05 criterion. H_{02} was therefore rejected. The results indicate that the PhET simulation group demonstrated substantially higher interest and achievement than students taught through the conventional method.

Gender Differences among Students Taught Using PhET Simulation

Table 2. Gender Differences in Interest and Achievement within the Experimental Group

Variable	Gender	N	Mean	SD	Mean Difference	t	df	p	Decision
Interest	Male	33	47.09	5.24	0.21	0.18	63	0.86	Not significant
	Female	32	46.88	4.46					
Achievement	Male	33	75.88	2.95	0.35	0.45	63	0.66	Not significant
	Female	32	75.53	3.35					

The male students exposed to PhET simulation obtained a mean interest score of 47.09 (SD = 5.24), whereas female students obtained 46.88 (SD = 4.46). The mean difference was only 0.21. The independent-samples t-test produced $t(63) = 0.18$, $p = .86$. Since the probability value exceeded .05, H03 was retained. Similarly, male students recorded an achievement mean of 75.88 (SD = 2.95), while female students recorded 75.53 (SD = 3.35). The difference of 0.35 was minimal and statistically insignificant, $t(63) = 0.45$, $p = .66$. H04 was therefore retained. The results indicate that PhET simulation produced comparable interest and achievement outcomes for male and female students.

Discussion

The first major finding revealed that students taught Biology using PhET simulation demonstrated significantly higher interest than students taught through the conventional instructional method. The finding may be explained by the interactive nature of simulation-supported learning. Unlike conventional instruction in which learners may primarily receive information from the teacher, PhET simulations provide opportunities to manipulate representations, observe changes and explore relationships among scientific concepts. The finding supports Okolo and Oluwasegun (2020), who reported that computer simulation positively influenced students' interest in cell division. It also corresponds with the findings reported by Nurul-Azzubairiyah and Enny (2022), in which students demonstrated favourable responses after participating in PhET-supported virtual laboratory activities. Such results suggest that technology-supported visualization and interaction can contribute to affective engagement with science. The result can also be viewed in relation to the importance of interest in learning. Harackiewicz et al. (2016) argued that interest promotes attention, persistence and engagement with learning activities. Students who can manipulate simulated processes and immediately observe the consequences of their actions may perceive Biology as more understandable and enjoyable. This may explain the substantially higher interest scores recorded by the experimental group. The second major finding showed that students taught with PhET simulation achieved significantly higher scores than their counterparts taught through the conventional method. The result suggests that interactive simulations supported students' understanding of the Biology concepts addressed during the intervention. This finding agrees with Najib et al. (2022), who reported positive effects of PhET interactive simulation activities on secondary school students' Physics achievement. It is also consistent with Cetinkaya and Kirilmazkaya (2022), who found favourable science learning outcomes from PhET-supported instruction. Furthermore, Tuyizere and Rutegwa (2024) reported that simulation-supported instruction enhanced conceptual understanding of protein synthesis among secondary school students. The achievement advantage may be associated with the capacity of simulations to represent processes visually and dynamically. In conventional Biology instruction, students may

be required to develop mental representations of processes from static diagrams and verbal explanations. PhET-supported instruction can complement those explanations with interactive visual information, potentially supporting connections between abstract explanations and observable representations. The finding is consistent with the theoretical assumptions underpinning the study. Dual Coding Theory suggests that information presented through complementary verbal and visual forms may be processed and represented through multiple cognitive routes. Similarly, the Cognitive Theory of Multimedia Learning emphasizes the importance of coordinating verbal and pictorial information in meaningful learning. The multimedia and interactive characteristics of PhET simulations therefore provide a plausible instructional basis for the superior achievement demonstrated by the experimental group.

Nevertheless, the finding differs from Yunzal and Casinillo (2020), whose study did not demonstrate the same level of positive effect of PhET simulation on students' performance. Differences among studies may be related to subject matter, duration of treatment, implementation procedures, teachers' competence, technological infrastructure, characteristics of participants and learning environment. Thus, the availability of simulations alone may not guarantee improved achievement; how simulations are integrated into instruction remains important.

The third finding established that male and female students exposed to PhET simulation did not differ significantly in their interest in Biology. The mean scores of 47.09 for males and 46.88 for females were nearly identical. This suggests that the interactive environment created through PhET simulation was similarly engaging for both genders. This result corroborates Okolo and Oluwasegun (2020), who reported no meaningful gender disadvantage in students' interest when computer simulation was employed. The finding indicates that the instructional characteristics responsible for increased engagement—visual representations, manipulation and active participation—may operate similarly among male and female learners. The fourth finding revealed no statistically significant difference between the achievement of male and female students exposed to PhET simulation. Male students obtained a mean score of 75.88, while female students obtained 75.53. The negligible difference indicates that both groups benefited comparably from the intervention. The finding is consistent with Liwhuliwhue, Ofoegbu and Asogwa (2023), who reported positive outcomes from PhET virtual laboratory simulation without a significant gender difference. It also supports the broader proposition that properly implemented technology-supported instruction can provide equitable opportunities for learners. However, the finding contrasts with Alabi, Mohammed and Yusuf (2023), who reported gender differences in students' scores associated with simulation. Variations in cultural setting, subject matter, sample composition, instructional implementation and access to technology may explain differences between findings.

Conclusion

The study established that PhET simulation instructional strategy is an effective approach for enhancing senior secondary school students' interest and academic achievement in Biology in the FCT, Abuja. Students taught through PhET-supported instruction demonstrated substantially higher interest and achievement than those taught using the conventional instructional method.

The study further established that the effectiveness of PhET simulation was not significantly influenced by gender. Male and female students exposed to the strategy recorded comparable levels of interest and achievement. PhET simulation can therefore be considered a potentially gender-inclusive instructional approach for Biology. The findings demonstrate the value of integrating interactive, technology-supported and learner-centred instructional resources into

secondary school Biology teaching, particularly for concepts that benefit from visualization and active exploration.

Recommendations

Based on the findings of the study, the following were recommended:

- i. Government should provide computers, projectors, reliable electricity and other ICT facilities required for effective utilization of interactive simulations. Government should also provide Biology teachers regular training and professional development on the pedagogical use of PhET simulations rather than merely on the operation of technological devices.
- ii. Curriculum developers should consider integrating simulation-supported instructional activities into the senior secondary school Biology curriculum.
- iii. School administrators should encourage and support teachers to integrate PhET simulations with appropriate classroom activities and monitor their contribution to students' learning outcomes.
- iv. Biology teachers should incorporate PhET simulations into classroom instruction, and PhET simulations should be made accessible to both male and female students because the findings indicate comparable benefits for both groups.

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