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Ameliorating Students' Cognitive Engagement and Critical Thinking in Chemistry: Testing the Potency of Practical-Based and Discussion-Based Approaches

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Abstract: *This research investigated if either Practical-Based Approach (PBA) or Discussion-Based Approach (DBA) could be more effective in ameliorating students' cognitive engagement and critical thinking ability in Chemistry. The study adopted a quasi-experimental research design. Chemistry Cognitive Engagement Inventory (CCEI) and Critical Thinking Ability Test (CTAT) were the instruments used for data collection. The reliability index of CCEI was ascertained using Cronbach Alpha, which gave reliability value of 0.86. The internal consistency of CTAT was tested using Kuder-Richardson (KR-21) formula which yielded a reliability value of 0.92. The population is 6,837 SS2 students offering chemistry in SSS in Dekina Local Government Area of Kogi State, Nigeria. Using multi-stage sampling techniques, a sample of 166 students drawn from 4 schools in Dekina LGA was selected. Two research questions and four null hypotheses guided the study. The research questions were answered using Mean and Standard Deviation scores while the null hypotheses were tested at 0.05 level of significance using results from Analysis of Covariance (ANCOVA). The study revealed that, the difference in the cognitive engagement and critical thinking ability of students taught chemistry using PBA and those taught using DBA was statistically significant in favour of PBA respectively* $\{F_{1,\ 165} = 138.100,\ P<0.05\}$ $\{F_{1,\ 165} = 188.900,\ P<0.05\}$. *There is no significant interaction effect of approaches and gender on the cognitive engagement and critical thinking ability of students in chemistry respectively* $\{F_{1,\ 165} = 1.765,\ P>0.05\}$ $\{F_{1,\ 165} = 5.005,\ P>0.05\}$. *It was recommended among others that; Chemistry teachers should be encouraged to use PBA during chemistry instruction to ameliorate students' cognitive engagement and critical thinking ability.*

Keywords: Practical-Based Approach (PBA), Discussion-Based Approach (DBA), Students' Cognitive Engagement, Critical Thinking Ability and Chemistry.

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INTRODUCTION

Chemistry teaching aims at equipping the learners with appropriate scientific and innovative knowledge and skills which will enable them to explore their surroundings and become more creative and self-reliant for national development. It refers to the science-based subject taught to students in their senior secondary school classes aimed at helping students to have clear knowledge about scientific reasoning and analytical problem solving with a molecular perspective and to provide students with the skills needed to succeed in post-secondary school and in the chemical industries (Ajayi, 2017). Chemistry is the central in the drive of global sustainable economic, science and technology development. It plays vital roles in food, clothing, housing, medicine and transportation. The important of chemistry to national development cannot be over-emphasized. Yet, students' cognitive engagement and critical thinking skill respectively in chemistry has been reportedly poor in Nigeria (Agamber, 2021; Kabiru, 2022). Thus, preparing the students to become successful individuals, chemistry teachers needs to ensure that their teaching is effective.

Learning by doing in science subjects, particularly in chemistry is very important in enabling students to understand what they are learning. This has been emphasized by various researchers and academics mostly those who advocate for learning by doing (Ajayi & Ogbeba 2017; Achimugu, 2018; Shana & Abulibdeh, 2020; Ajayi & Audu, 2023). Therefore, Students' cognitive engagement is very important in supporting their critical thinking toward a particular discipline. Students engagement plays an important role in reshaping their behaviours towards learning. Clinton-Lisell, Strouse and Langowski (2024) opines that, cognitive engagement involves the psychological investment of the student in the learning process. It is marked by the effort made by the learner to understand what is studied and to reach the highest levels of comprehension on a specific area of study. By implication, cognitive engagement is seen as the time and effort students invest during chemistry classroom instruction. Students cognitive engagement reflects the degree of curiosity, involvement, optimism and passion that learners show when they are learning or being taught. Thus, since cognitive engagement focuses on students' level of investment or involvement in learning, there is need for chemistry teachers to ensure the use of effective instructional styles that are capable of ameliorating students' cognitive engagement and invariable ameliorate their critical thinking.

Critical thinking is the objective analysis and evaluation of an issue to form judgement. Critical thinking is the ability to think clearly and rationally about what to do or what to believe and it includes the ability to engage in reflective and independent thinking (King, Goodson and Rohani, 2017). Critical thinking is the ability to logically and rationally consider information. Rather than accepting arguments and conclusions presented, a person with strong critical thinking skills will question and see to understand the evidence provided. He will look for logical connections between ideas, consider alternative interpretations of information and evaluate the strength of arguments presented. Good critical thinkers can draw reasonable conclusions from a set of information and discriminate between useful and less useful details to solve a problem or make a decision. Similarly, Bolaji (2019) observes that a critical thinker

is able to deduce consequences from what he knows, and he knows how to make use of information to solve problems, and to seek relevant sources of information to inform himself/herself. Learners of chemistry need critical thinking skills to evaluate and improve their creative ideas to make firm decisions

Critical thinking is one of the aspects of thinking that has been accepted as a way to overcome the difficulties and to facilitate the access to information in life. Yenice (2017) posits that the main target of science teaching is to develop critical thinking skills and abilities in students and this can only be achieved through appropriate teaching approaches. Demirhan and Besoluk (2019) observed that critical thinking enables students to acquire the necessary abilities to analyze information objectively and make a reasoned judgement which enhances learning outcome. However, the authors lament the inability of science teachers to teach students in a way that they will 'think outside the box' to be able to solve problem on their own. Thinking outside the box could enable learners cope with future challenges which could be in other areas of human endeavour.

The quality of education that a teacher provides to students is highly dependent upon what teachers do in the classroom. Foong (2019) lamented that the teaching styles used by most teachers could not guarantee student-centered learning that allows learners to construct scientific knowledge and skills. The author further opines that critical thinking is one of several learning and innovative skills necessary to prepare students for post-secondary education and professional disciples. Thus, the learning paradigm should shift from low level thinking skills to learning higher order thinking skills such as prediction, evaluation and syntheses. Since, the poor students' cognitive engagement and critical thinking has often been blamed on poor teaching approaches. Thus, there is need for chemistry teachers to use effective instructional approaches that could provide an enabling environment for students to think critically both in and outside the classroom.

Practice-based approach (PBA) is one of promising students' centered methodologies that actively engage learners in the learning process. Science subjects especially chemistry, require more experience, tangible together with concrete examples throughout the learning endeavour. Colardyn and Bjornavold (2020) opine that, chemistry is more practical than theoretical because different knowledge, skills and attitudes have to be developed among the learners through the repetition of practical or hands-on experiences. Practice-based approach involve the regular integration of practical or experimental session(s) during classroom instruction in order to equip learners with abilities to solve real life problems. Practice-based approach may help learners to link the content learnt with the real-world situations and to enhance their curiosity that in turn leads to the acquisition of higher-order thinking and problem-solving skills. PBA involve the process of learning that combines theory and practice, and emphasizes the importance of practice in generating knowledge. PBA is a learner-centered approach that combines theory with practice. In PBA, students apply their learning through a reflective process and receive personalized feedback. With practice-based learning approach, you combine theory and experimental experience with a strategic, reflective process throughout the period of learning.

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Discussion-based approach (DBA) is a teaching approach that involve students and teachers exchanging ideas about a topic or problems. DBA is open-ended, collaborative exchange of ideas among a teacher and students or among students for the purpose of furthering students thinking, understanding and problem-solving (Wilkinson, 2020). In DBA, participants present multiple points of view, respond to the ideas of others, and reflect on their own ideas in an effort to build their knowledge, understanding or interpretation of the concept or phenomenon. Discussion may occur among small group of students, whole class and be teacher-led or student-led. However, in this study, DBA is the collaborative exchange of ideas among a teacher and students. Hence, the study investigated if either practical-based approach or discussion-based approach could be more effective in ameliorating students' cognitive engagement and critical thinking ability.

Purpose of the Study

The purpose of this study was to investigate if either Practical-Based Approach (PBA) or Discussion-Based Approach (DBA) could be more effective in ameliorating students' cognitive engagement and critical thinking ability in Chemistry. Specifically, the study was set out to:

1. Ascertain the difference in the cognitive engagement ratings between students taught chemistry using PBA and those taught using DBA.
2. Find out the interaction effect of approaches and gender on students' cognitive engagement ratings in chemistry.
3. Determine the difference in the critical thinking ability scores between students taught chemistry using PBA and those taught using DBA.
4. Find out the interaction effect of approaches and gender on students' critical thinking ability scores in chemistry.

Research Question

The following research question guided this study

1. What is the difference in the mean cognitive engagement ratings between students taught chemistry using Practical-Based Approach (PBA) and those taught using Discussion-Based Approach (DBA)?
2. What is the difference in the mean critical thinking ability ratings between students taught chemistry using PBA and those taught using DBA?

Hypotheses

The following null hypotheses guided the study:

1. The difference in the cognitive engagement ratings of students taught chemistry using Practical-Based Approach (PBA) and those taught using Discussion-Based Approach (DBA) is not statistically significant.
2. There is no significant interaction effect of approaches and gender on the cognitive engagement ratings of students in chemistry.
3. There is no significant difference in the critical thinking ability scores between students taught chemistry using PBA and those taught using DBA

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4. There is no significant interaction effect of approaches and gender on the critical thinking ability scores of students in chemistry.

Research Design and Procedure

The study adopted pre-test, post-test non-equivalent quasi-experimental research design. The study area is Anyigba, Kogi State, Nigeria. Anyigba is a town in Dekina Local Government Area of Kogi State located between latitudes $7^0$15'N - $7^0$29'N and longitudes $7^0$11'E - $7^0$32'E and with an average altitude of 385 meters above sea level and total land mass area of 420 Sq. Km^2 and has an estimated population of 189, 976 (NPC, 2016). The major ethnic groups in Anyigba are Igala, Ebira, Gbagyi, Okun (Yoruba), Bassa, Nupe, Ogori, Igbo, Idoma, Hausa and so on. The population for this study comprises all the students offering chemistry in senior secondary school two in Anyigba, numbering 6,837 students from all the 56 approved senior secondary schools in Anyigba (Kogi State STETSCOM, 2022). The sample of this study was made up of 166 SS2 students that were drawn from 4 schools in Dekina Local Government Area of Kogi State, Nigeria using purposive sampling technique. Chemistry Cognitive Engagement Inventory (CCEI) and Critical Thinking Ability Test (CTAT) were the instruments used for data collection.

Chemistry Cognitive Engagement Inventory (CCEI) was a researcher made 25 items inventory which was intended to help students express their engagement level during chemistry instruction. Each of the items is a 4-point Likert modified rating scale with 4 response options. The options are NE (Not Engaged), SE (Slightly Engaged), ME (Moderately Engaged) and VE (Very Engaged). The items were developed from information acquired through review of relevant literature by the researchers. Critical Thinking Ability Test (CTAT) was adapted from Watson and Glizer (2022) Critical Thinking Ability Test. The test items looked at individual's ability to make correct inferences, recognize assumptions, make deductions, come to conclusion, interprets and evaluate arguments. Thus, the critical thinking test adapted in this study is based on recognizing assumptions, evaluating arguments and drawing conclusion. CTAT is a 30 multiple choice tests made of short statements and conclusions to be answered within 45 minutes. Students were to read through the statements carefully and come out with definite conclusions.

Chemistry Cognitive Engagement Inventory (CCEI), Critical Thinking Ability Test (CTAT), the lesson notes were face validated by presenting them to three experts in Science Education/Measurement and Evaluation. The items were scrutinized by these expects. Corrections and suggestions arising from these experts were used to review the instrument and the instructional packages. CCEI and CTAT upon validation were trial-tested to establish the reliability of the instruments by administering it to a randomly selected 41 SS2 students of a senior secondary school which is not part of the schools selected for this study. After 1 week of 8 periods of teaching, the CCEI and CTAT was administered with the help of the research assistants. Cronbach Alpha was used to ascertain the reliability index of CCEI which gave reliability value of 0.86. Kuder-Richardson (KR-21) formula was used to test internal consistency of CTAT which gave reliability value of 0.92.

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Chemistry Cognitive Engagement Inventory (CCEI) and Critical Thinking Ability Test (CTAT), was administered as pre-test by the teachers that served as research assistants. This lasted for one week before actual teaching commences. During the main study, the four schools were assigned randomly to Group A (Practical-Based group) and group B (Discussion-based group). intact classes were assigned Group A is the Practical-Based group. In this group all lessons taught were accompanied with practical or experiments for the duration of six weeks of teaching. Group B is the discussion group which consist of students who were taught only the theory aspect of the same chemistry topic without any practical for a period of six weeks. During lessons, the groups were taught the same chemistry topics such as identification of fats and oils, determination of degree of purity, crystallization and solubility. At the end of these actual teaching periods, the pre-test was reshuffled and administered as post-test which lasted for one week. Descriptive statistics of mean and standard deviation scores were used to answer the research question, while the inferential statistic of Analysis of Covariance (ANCOVA) were used to test the null hypotheses at 0.05 level of significance.

RESULTS

Presentations in this section are based on research question and null hypotheses

Research Question One

What is the difference in the mean cognitive engagement ratings between students taught chemistry using Practical-Based Approach (PBA) and those taught using Discussion-Based Approach (DBA)? The answer to research question one is presented on Table 1.

Table 1: Mean Cognitive Engagement and Standard Deviation Scores of Students Taught Chemistry using PBA and DBA

Group	N	PRE- CCEI		POST- CCEI		Mean Gain
		$\tilde{x}$	δ	$\tilde{x}$	δ	
PBA	81	1.13	0.12	3.69	0.21	2.56
DBA	85	1.14	0.15	2.03	0.17	0.89
Mean diff.		-0.01		1.66		1.67

Table 1 reveals the mean cognitive engagement rating and standard deviation scores of students taught chemistry using Practical-Based Approach (PBA) and Discussion-Based Approach (DBA). The data in Table 1 show that the overall mean difference between students in PBA and DBA groups was 1.67 in favour of PBA. This implies that students in PBA group had higher cognitive engagement that students in DBA group.

Research Question Two

What is the difference in the mean critical thinking ability scores between students taught chemistry using Practical-Based Approach (PBA) and those taught using Discussion-Based Approach (DBA)? The answer to research question two is presented on Table 2.

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Table 2: Mean Critical Thinking and Standard Deviation Scores of Students Taught Chemistry using PBA and DBA

Group	N	PRE- CTAT		POST- CTAT		Mean Gain
		$\tilde{x}$	δ	$\tilde{x}$	δ	
PBA	81	8.19	1.15	25.71	3.07	17.52
DBA	85	8.17	1.13	17.83	2.16	9.66
Mean diff.		0.02		7.88		7.86

Table 2 reveals the mean critical thinking ability rating and standard deviation scores of students taught chemistry using Practical-Based Approach (PBA) and Discussion-Based Approach (DBA). The data in Table 1 show that the overall mean difference between students in PBA and DBA groups was 7.86 in favour of PBA. This implies that students in PBA group had higher critical thinking ability that students in DBA group

Hypothesis One
The difference in the cognitive engagement ratings of students taught chemistry using Practical-Based Approach (PBA) and those taught using Discussion-Based Approach (DBA) is not statistically significant. The answer to hypothesis one is presented on Table 3.

Table 3: ANCOVA Result for Cognitive Engagement Rating of Students Taught Chemistry using PBA and DBA

Source	Type III sum of squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected model	176.902[a]	2	88.451	.221	.000	.402
Intercept	38.002	1	38.002	189.009	.000	.322
TPr^{CCEI}	.458	1	.458	.211	.196	.000
Method	39.194	1	39.194	138.100	.000	.762
Method*Gender	.076	1	0.76	1.765	.239	.002
Error	6.006	162	.083			
Total	2419.071	166				
Corrected Total	117.800	165				

a. R squared = .561 (Adjusted R Squared= .569)

ANCOVA Test result in Table 3 reveals that difference in the cognitive engagement ratings between students taught chemistry using Practical-Based Approach (PBA) and those taught using Discussion-Based Approach (DBA) is significant $\{F_{1,\ 165} = 138.100, P<0.05\}$. The null hypothesis is therefore rejected. This implies that the difference in the cognitive engagement

rating between students taught chemistry using PBA and those taught using DBA is significant in favour of PBA. Meanwhile, the effect size of 0.762 is considered as large effect size. This implies that, only 76.2% of the difference in the cognitive engagement rating scores between the group was explained by treatments. Hence, the difference in the cognitive engagement rating of students between the group has a large statistical effect size.

Hypothesis Two

There is no significant interaction effect of approaches and gender on the cognitive engagement ratings of students in chemistry. The answer to hypothesis two is presented on Table 3.

The data analysis in Table 3 is used to explain hypothesis 2. The table presents an ANCOVA result for cognitive engagement rating of students taught chemistry using Practical-Based Approach (PBA) and Discussion-Based Approach (DBA). The table presents the interaction effect of approaches and gender. The data in Table 3 reveals that there is no significant interaction effect of approaches and gender on the mean cognitive engagement rating of students in chemistry $\{F_{1,\ 165} = 1.765,\ P > 0.05\}$. The null hypothesis is therefore not rejected. Meanwhile, the effect size was 0.002 which is considered as very small effect size. This implies that, only 0.2% of the interaction in the cognitive engagement rating between the group was explained by treatment and gender. The interaction of treatments and gender on learners' engagement has very small statistical effect size. Therefore, there is no need for separation of treatment for male and female students since PBA can be used successfully for the two groups to enhance their cognitive engagement during chemistry instruction.

Hypothesis Three

There is no significant difference in the critical thinking ability scores between students taught chemistry using Practical-Based Approach (PBA) and those taught using Discussion-Based Approach (DBA)**.** The answer to hypothesis three is presented on Table 4.

Table 4: ANCOVA Result for Critical Thinking Scores between Students Taught Chemistry using PBA and DBA

Source	Type III sum of squares	*df*	Mean Square	F	Sig.	Partial Eta Squared
Corrected model	2376.452[a]	2	1188.226	135.001	.000	.402
Intercept	119.000	1	119.000	328.001	.000	.322
TPr^{CTAT}	.748	1	.748	1.765	.280	.000
Method	299.001	1	299.001	188.900	.000	.819
Method*Gender	.119	1	.119	5.005	.110	.004
Error	12.001	162	1.233			
Total	5419.001	166				
Corrected Total	2671.009	165				

b. R squared = .51 (Adjusted R Squared= .67)

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ANCOVA Test result in Table 4 reveals that difference in the critical thinking ability scores between students taught chemistry using Practical-Based Approach (PBA) and those taught using Discussion-Based Approach (DBA) is significant {$F_{1, 165}$ =188.900, P<0.05}. The null hypothesis is therefore rejected. This implies that the difference in the critical thinking ability scores between students taught chemistry using PBA and those taught using DBA is significant in favour of PBA. Meanwhile, the effect size of 0.819 is considered as large effect size. This implies that, only 81.9% of the difference in the critical thinking ability scores between the group was explained by treatments. Hence, the difference in the critical thinking ability scores of students between the group has a large statistical effect size.

Hypothesis Four
There is no significant interaction effect of approaches and gender on the critical thinking ability scores of students in chemistry. The answer to hypothesis four is presented on Table 4.

The data analysis in Table 4 is used to explain hypothesis 4. The table presents an ANCOVA result for critical thinking ability scores of students taught chemistry using Practical-Based Approach (PBA) and Discussion-Based Approach (DBA). The table presents the interaction effect of approaches and gender. The data in Table 4 reveals that there is no significant interaction effect of approaches and gender on the mean critical thinking ability scores of students in chemistry {$F_{1, 165}$ =5.005, P>0.05}. The null hypothesis is therefore not rejected. Meanwhile, the effect size was 0.004 which is considered as very small effect size. This implies that, only 0.4% of the interaction in the critical thinking ability scores between the group was explained by treatment and gender. The interaction of treatments and gender on students' critical thinking ability scores has very small statistical effect size. Therefore, there is no need for separation of treatment for male and female students since PBA can be used successfully for the two groups to enhance their critical thinking ability in chemistry classroom.

DISCUSSION OF FINDINGS

The study investigated if either Practical-Based Approach (PBA) or Discussion-Based Approach (DBA) could be more effective in ameliorating students' cognitive engagement and critical thinking ability in Chemistry. The finding of this study revealed that the difference in the cognitive engagement ratings between students taught chemistry using Practical-Based Approach (PBA) and those taught using Discussion-Based Approach (DBA) is significant. This finding agrees with Abdelhamid (2019), who found that a percentage of 79% from the total students enrolled in architectural course agreed that they had benefited from experiments carried out during site visit and also argued that sometimes teachers theoretical comments or explanations are not clear enough for them and that experimental study is very useful as it brought them into direct contact with the space on the real world. The finding agrees with Ajayi and Ogbeba (2017), findings that hands-on activities (through experimentation) is an effective strategy in ameliorating students' academic achievement and scientific process skills in chemistry than conventional teaching method. In the same vein, this finding is also in line with Agamber, Achor, Ajayi (2019) findings that teaching biology with practical work to students as frequently as possible is more rewarding and beneficial to learners in terms of enhancing

motivation and self-efficacy belief in solving biology related problems likely reason for this outcome may be attributed to the fact that PBA helped the learners to frequently reflect, explore and learn from the real-world experience.

The finding of this study further revealed that difference in the critical thinking ability scores between students taught chemistry using Practical-Based Approach (PBA) and those taught using Discussion-Based Approach (DBA) is significant in favour of PBA. This finding is in line with Nja and Neji (2017) findings that the use of kitchen resources enhanced the performance of students exposed to experimentation of kitchen resources during the teaching of Home Economic compared to those taught without experimentation. This finding collaborates with John and Asikong (2020) finding that regular exposure students to experiments have rewarding learning outcome and retention in students than conventional method in waves. Thus, the likely reason for this outcome may also be connected to the fact that the use of PBA provides a format for students to see how knowledge is developed through the process of reflecting, probing, investigating, analyzing, synthesizing, discovering, discovering and critical thinking they undertake thereby enhancing conceptual understanding compared to discussion-based approach that only promotes passive learning. This finding of this study also revealed that there is no significant interaction effect between approach and gender on engagement and critical thinking in chemistry. It shows that PBA is superior to the discussion-based irrespective of gender in fostering students' learning engagement and academic performance in chemistry. Therefore, there is no need for separation of instructional strategy for male and female students since Practical-Based approach can be used successfully for the two groups.

CONCLUSION

The study has established that practical-based approach is more rewarding and beneficial to students in terms of ameliorating students' cognitive engagement and critical thinking ability when compared to discussion-based approach. It was evident from the finding the study that there is no significant interaction effect between methods and gender. Therefore, Practical-Based teaching approach can be used successfully for the two groups to ameliorate learners' cognitive engagement and critical thinking ability in chemistry. The following recommendations were made:

1. Chemistry teachers should be encouraged to use practical-based approach during chemistry instruction to ameliorate students' cognitive engagement and critical thinking ability.
2. Practical-Based approach is not gender sensitive. Hence, both male and female students should be involved in practical or experiments during chemistry instruction to enhance their cognitive engagement and critical thinking ability.
3. Relevant school authorities should provide laboratory facilities and ensure strict monitoring and supervision to ensure that practical activities are carry out regularly during chemistry instruction so as to enhance learners' cognitive engagement and critical thinking ability.

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