Improving students' achievement in chemistry: comparative effectiveness of conceptual modelling and conceptual blending

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ABSTRACT

The study looked at how conceptual modelling (CM) and conceptual blending (CB) affected students' achievement in chemistry. This study employed a quasi-experimental design. In this study, 274 seniors secondary (SSII) chemistry students from six coeducational secondary schools in the state were randomly selected using simple random sampling. The information was gathered using the chemistry achievement test (CAT). It was used for pre-test and post-test to evaluate students' achievement in chemistry. All groups received these tests before and after a six-week course of therapy. The mean/average scores of the 3 groups on the pre-test and post-test were compared using analysis of covariance (ANCOVA) of the CAT data. The study discovered that CM, as opposed to CB, had a significantly bigger effect on students' achievement in chemistry. Chemistry achievement was significantly higher with CB than with the lecture approach (LA). According to the study, when compared to the LA, CM and CB are more effective teaching strategies for raising students' achievement in chemistry. Furthermore, it was discovered that CM was the most successful approach. It was suggested, among other things, that chemistry instructors incorporate CM into their chemical lessons.

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1. INTRODUCTION

Chemistry is a branch of science that examines many substances' properties, interactions, composition, and structure. It is a fundamental scientific field essential to understanding the world around us and many different businesses, including manufacturing, agriculture, and pharmaceuticals [1]. In Nigeria, teaching chemistry in senior secondary (SSII) grades/schools is essential because it gives students a solid foundation in basic chemical principles, develops their problem-solving and critical thinking abilities, and helps them recognise the importance of chemistry in everyday life [2]. Students who study chemistry can contribute to the growth of science and technology in Nigeria and abroad and acquire the knowledge and skills necessary to excel in postsecondary education and the workforce. Despite this significance, a lot of data suggests that many students continuously have subpar grades over the years, even if many find chemistry fascinating and decide to study it in SSII schools [3]. It has been established by the West African Examination Council (WAEC) Chief Examiner's Reports (2018–2023) [4] that students' poor achievement in chemistry is an issue. The low achievement in the discipline of chemistry may be attributed to instructors' deficient implementation of the chemistry curriculum, which results from ineffective teaching methodologies.

According to Odesa and Dore [5], the lecture teaching method is a teaching strategy where the teacher presents material to the class in its final form. When there are not enough opportunities for questions, the students take notes and actively listen. It is one of the oldest teaching techniques [6]. The lecture approach (LA) has several drawbacks, including a propensity to involve students passively during education and a failure to encourage critical and creative thinking in them [7], [8]. It has been proposed that improving student accomplishment requires active teaching practices that encourage student participation and focus on areas of weakness during instruction [9]. Conceptual modelling (CM) and conceptual blending (CB) are two of these active teaching techniques that are suggested for chemistry education.

CM involves the utilisation of representations like diagrams, symbols, analogies, and mental models to aid understanding. It expresses ideas and concepts in a symbolic or visual format to facilitate comprehension and communication [10], [11]. To facilitate students' understanding of complicated concepts, CM in education entails the creation of visual representations of abstract ideas [12]. This can involve illuminating links, procedures, or structures within a topic area using diagrams, charts, graphs, or other visual aids. CM is practically applied in chemistry classroom by the teacher by identify the chemistry concept, that is choose abstract concepts suitable for modelling, introduce the concept with context by briefly explanation of the concept using real-world examples or problems to arouse curiosity, present an initial model through provision of a visual or symbolic model, encourage student construction of models, facilitate model discussion by engaging students in peer-review or group discussions where they compare and critique each other's models based on accuracy and clarity, refine and correct misconceptions, apply the model to problem-solving and evaluating understanding through quizzes or oral presentations where students explain a concept using their developed models. Empirical studies have demonstrated the beneficial effects of implementing CM in the classroom on students' academic achievement. Francis and Baba [13] discovered that students understood and retained material better than those who did not use this visual aid regarding concept maps, which they developed to arrange and depict their knowledge. Similarly, Taber and García-Franco [14] meta-analysis discovered that visual aids like charts and diagrams were among the best teaching techniques for raising student learning results.

CB involves integrating elements from multiple mental spaces to produce new meaning. This strategy is effective in making abstract chemistry concepts relatable by blending scientific ideas with real-life analogies or cross-domain concepts. It is a cognitive process whereby several concepts or ideas are combined to provide original and creative solutions [15], [16]. Making connections between seemingly unrelated things is creative thinking that enables people to generate new ideas and insights [17]. Through CB, students might be inspired to think critically and draw connections between seemingly unrelated ideas, which could lead to a deeper comprehension of the content being studied [18]. Studies have indicated that integrating CB in the classroom can yield favourable results for students' academic achievement. For instance, students who participated in CB exercises showed more substantial levels of creativity and problem-solving abilities than those who did not, according to a study by Ates and Aktamis [19]. Similarly, research by Yang *et al*. [20] found that students who were taught to mix concepts better performed on tests that evaluated their ability to think critically and reason analytically. CB is practically applied in chemistry classroom through selection of the concept for blending, introduction of familiar real-life concept, presentation of the scientific concept, creation of a blended scenario (blend elements from both domains (scientific and real-life) to create an integrated explanation), visualize the blending through diagrams or storytelling to visualize the blend, facilitate student-generated blends, critically analyze the blends, application of the new contexts, and assessment of blended understanding. The main differences between the two approaches lies in their primary focus. CM aims to represent a system or domain in a structured, understandable way, whereas CB explores how different concepts can be combined and merged to create new meaning or understanding.

The two well-liked instructional methodologies are suggested when teaching chemistry: CM and CB. CB combines several concepts to provide a more comprehensive grasp of the subject matter. In contrast, CM uses diagrams, charts, and other visual aids to depict chemical concepts and relationships. However, CM is expected to be more effective in comparison to CB. This is because CM makes it easier for students to visualise and comprehend abstract chemistry concepts, which improves retention and knowledge of the subject matter. Nevertheless, a full investigation into their relative effectiveness in the particular chemistry context at the Delta State secondary school level has not yet been conducted. Thus, the major aim of this study is to determine the effective these two tactics are in comparison to one another.

The biological and psychological traits that separate males and females are called "sex" [21]. In this study, "sex" refers exclusively to male and female students taking chemistry classes in a classroom setting. Therefore, another reason for doing this study is to ascertain whether or not the utilisation and application of CM and CB affect male and female students' chemistry achievement differently. Another goal of the research is to ascertain whether or not students' sex affects the efficacy of CM and CB as teaching methods.

In terms of their understanding of chemical principles, students who received teaching using CM significantly outperformed their traditional method peers, according to a study by Oni *et al*. [22].

The researchers concluded that CM can help students become more proficient in chemistry by providing abstract ideas with a visual representation. In a different study, Wu and Shah [23] examined the effect of CM on students' achievement in organic chemistry. The researchers found that students taught using CM had a deeper understanding of organic chemistry principles and performed better on exams than students taught using traditional approaches. In a different study, Talanquer [24] examined the role CB plays in assisting students in developing their conceptual knowledge of chemical reactions. The study results demonstrated that students who engaged in CB activities were more adept at connecting different chemical concepts and applying their expertise in more meaningful ways. Furthermore, Omeje [25] looked at the effect of CB on students' ability to solve chemistry issues/topics. The results of the study showed that students who engaged in CB activities performed better in chemistry classes because they were more adept at solving issues creatively and effectively. This suggests conceptual mixing can enhance students' problem-solving skills and academic achievement.

While previous research has shed light on how CM and CB impact students' performance in chemistry. One big gap is that, as far as the researchers know, there are not any studies that look at how CM and CB effect students' performance in chemistry. Most of the research that has been done so far has been in different places or schools, so it is important to fill this gap and find out how well CM and CB work for students' chemistry grades in this area. Another gap in the studies is that not enough attention has been paid to how CM and blending affect students' performance in chemistry.

This study highlights the inconsistencies in research findings and the inevitability to offer empirical literature on how CM and CB affect students' achievement in chemistry, and the insufficiencies in existing literature. This will address existing gaps in literature. The purpose of this study is: i) the variation in students' average achievement scores when teaching chemistry using CM, CB, and LA; ii) the variation in the achievement scores between male and female students receiving CM instruction in chemistry; and iii) the disparity between male and female students' achievement scores in chemistry classes taught using CB.

The following are the formulated hypotheses for the study: i) H_{01}: the average achievement scores of students tutored chemistry utilising the CM, CB, and LA do not significantly differ (specific hypothesis regarding the comparison of the effectiveness); ii) H_{02}: the average achievement scores of male and female students tutored chemistry using CM do not differ significantly, and iii) H_{03}: the average achievement scores of male and female students tutored chemistry using CB do not differ significantly.

2. METHOD

2.1. Design of the study

The three groups were used in this quasi-experimental study: one for CM, one for CB, and a control group that received standard lecture training. In a quasi-experimental design, researchers do not have complete control over assigning participants to various groups, as in an experimental design with random assignment. The teaching methods employed are CM and CB as interventions for two groups (group 1 and group 2). The LA was concurrently used for the group 3 (control group). Consequently, the two intervention/treatment groups (CM and CB) underwent interventions, while the lecture or control group received no therapy. The observed disparities in learning outcomes were attributed to treatment. In this study, there was strict control of other variables that might affect the study results.

For students' prior ability in chemistry, this was controlled with the use of pre-test and statistically addressed by employing pre-test scores as covariates in the analysis of covariance (ANCOVA) for the post-test scores. To mitigate the influence of the teacher variable/background on the experimental outcomes, the researcher developed lesson plans utilised for equally the experimental and control groups. The researcher conducted micro-teaching sessions for the educators to guarantee the attainment of comparable effectiveness and performance. The study lasted six weeks. This period was deemed sufficient to regulate the impact of duration on the study results. The assessment of the dependent variable at two distinct time points may provide divergent outcomes. The post-test was conducted for both groups concurrently one week following the conclusion of the treatment. To control for external variables such as influence of different learning environments and students' motivation, the researchers ensured that all groups received similar material and were under equal conditions. Pre-test and post-test utilisation to evaluate students' achievement/gain levels before and after the intervention/treatment, thereby isolating the effects of the experimental setting. use of previous West African Senior School Certificate Examination (WASSCE) chemistry examination papers (validated assessment items) and the establishment of a classroom atmosphere that is friendly, inclusive, and fosters cooperation and positive interactions.

2.2. Sample of the study

The survey included 19,395 SSII students enrolled in chemistry courses in three senatorial districts of Delta State. The Post Primary Education Board's Academic Record Unit in Asaba, Delta State, 2024, supplied this. The six coeducational secondary schools in Delta State provided the sample of 274 SSII chemistry students for this study. The two schools were chosen using a random sampling technique for each state senatorial district. Slips of paper with the names of the schools in each district scrawled on them were then put in separate hats, folded, and combined. A straightforward random sampling strategy was applied using the draw-from-the-hat method. Each school received two picks from distinct hats. Up until the six schools were acquired, there was pick and switch.

2.3. Research instruments

The instrument utilised to collect the data was the chemistry achievement test (CAT). The 50 items with 4-options multiple choice objectives test the two concepts: electrolysis and redox reactions were taken from previous WASSCE chemistry question papers for the CAT. The content validation of the CAT instrument was based on the specs table. To establish the reliability of the instrument, the Kuder-Richardson 21 was employed to assess CAT's dependability. The CAT was administered to 27 SSII students taking chemistry in an Edo State school outside the research's coverage area as part of a pilot trial. After evaluating the students' answers using Kuder-Richardson 21, the dependability coefficient was discovered to be 0.77.

2.4. Procedure and analysis

The control group received LA type of instruction, the CB group received instruction integrating multiple concepts to create a deeper understanding, and the CM group received instruction using visual aids and diagrams to represent chemical concepts. Pre-test and post-test utilising CAT were administered to each group before and during the six-week therapy period to evaluate the student's progress in chemistry. ANCOVA was used to analyse data obtained with the assistance of CAT to compare the three groups' mean pre-and post-test scores. For a quasi-experimental study like this, ANCOVA helps statistically to remove the proportion of the variance of the dependent variable that were there before the experiment. More so, the error variance that occurred in the analysis was reduced through ANCOVA. A post-hoc test techniques are used to deal with violations of assumptions. ANCOVA was employed to account for variables such as students' initial abilities, motivational influences, or variations in instructional approaches. This isolates the genuine effect of the intervention by eliminating the impact of confounding variables.

3. RESULTS AND DISCUSSION

The effectiveness of CM and CB on students' achievement in chemistry was examined. The data generated and analysed are presented and interpreted in Tables 1 to 4, along with a comprehensive discussion this section.

- H_{01}: the average achievement of students taught chemistry using CM, CB, and those imparted using LA do not significantly differ.

At pre-test, students instructed CM had an average of 52.22, students tutored with CB had an average of 50.77, while students instructed using the LA had a pre-test score of 45.60. However, at the post-test, the CM group had an average of 69.86, and an average gain of 17.64. The CB group at the post-test was an average of 63.35, and an average gain of 12.58. Concurrently, the lecture group had a post-test mean of 53.26, and an average gain of 7.66. Thus, the results show that students instructed with CM and CB attained an enhanced achievement than the control group. In effect, CM proved to be superior to CB and the LA in boosting students' achievement. Conversely, the CB proved to be better in comparison to the LA in improving students' academic achievement.

Table 1. Comparison of achievement of students instructed chemistry using CM, CB, and LA methods by ANCOVA

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	3989.803	3	1329.934	16.675	.000
Intercept	43077.287	1	43077.287	540.111	.000
Pre-test	3.621	1	3.621	.045	.831
Teaching approaches	3944.864	2	1972.432	24.731	.000
Error	21534.201	270	79.756		
Total	1108373.000	274			
Corrected total	25524.004	273			

Table 1 illustrates the significant differences in average achievement between students taught chemistry by CM, CB, and LA [F(2, 270)=24.731, p=0.000]. Therefore, the null hypothesis is refuted. On this, students who learned chemistry through CM and blending had mean accomplishment scores that were noticeably different from those who knew the material through lectures. A Scheffe post-hoc analysis was performed to determine the direction of the differences, and the results are shown in Table 2. The mean achievement scores of students who learned chemistry through CM and CB varied statistically significantly (p=0.001), with a considerable preference for CM, as shown in Table 2. It demonstrates that the mean achievement scores of students who learned chemistry using CM compared to the LA differ significantly (p=0.000). This discrepancy supports CM. Additionally, it shows that the mean achievement scores of students taught chemistry by CB as opposed to the LA differ statistically significantly (p=0.000), preferring CB. This demonstrates that CM is the first step towards CB in the direction of differences. This suggests that CB, not CM, was the most effective way to raise students' achievement in chemistry.

Table 2. Scheffe post-hoc analysis on significance of mean difference in achievement between groups

(I) Method	(J) Method	Average difference (I-J)	Std. Error	Sig.	95% confidence interval for difference	
					Lower bound	Upper bound
CM	CB	4.482	1.340	.001	1.845	7.120
	LA	9.246	1.315	.000	6.657	11.834
CB	CM	-4.482	1.340	.001	-7.120	-1.845
	LA	4.763	1.342	.000	2.122	7.405
LA	CM	-9.246	1.315	.000	-11.834	-6.657
	CB	-4.763	1.342	.000	-7.405	-2.122

- H_{02}: the mean achievement scores of male and female students taught chemistry using CM do not differ significantly.

Table 3 shows no significant difference in the average achievement scores between male and female students taught chemistry using CM (F(1, 89)=0.206, p=0.651). The null hypothesis is so accepted. Therefore, when it comes to average achievement ratings, there is no discernible difference between male and female students who learn chemistry using CM. This demonstrates that CM and CB are not gender sensitive. This suggests that both teaching strategies are gender friendly. Thus, they can be used without recourse to students' gender.

Table 3. Comparing male and female students' average achievement scores in chemistry classes taught by CM using ANCOVA

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	100.005	2	50.003	.541	.584
Intercept	19637.341	1	19637.341	212.489	.000
Pre-test	88.854	1	88.854	.961	.329
CM	19.000	1	19.000	.206	.651
Error	8224.995	89	92.416		
Total	427500.000	92			
Corrected total	8325.000	91			

- H_{03}: the average achievement scores of male and female students taught chemistry using CB do not differ significantly.

Table 4 shows no significant difference in the average achievement scores between male and female students taught chemistry through CB (F(1, 83)=2.734, p=0.102). The null hypothesis is so accepted. Therefore, there is no discernible difference between male and female students who learned chemistry through CB in terms of mean achievement scores. This establishes that CM and CB are not gender sensitive. This suggests that both teaching strategies are gender friendly. Thus, they can be used without recourse to students' gender.

Table 4. Comparing male and female students' average achievement scores in chemistry classes taught using CB using ANCOVA

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	276.317	2	138.158	1.609	.206
Intercept	15649.164	1	15649.164	182.205	.000
Pre-test	111.168	1	111.168	1.294	.259
CB	234.799	1	234.799	2.734	.102
Error	7128.671	83	85.888		
Total	348865.000	86			
Corrected total	7404.988	85			

According to the study, students who received chemistry instruction through CM outperformed students who received instruction by CB in terms of marks. The study results showed that students who received their chemistry instruction through CM outperformed those who received it via lecture. This might result from CM, making the content more dynamic and engaging for students, improving their comprehension and memory of the ideas. This research supports the findings of Francis and Baba [13], who found that, in comparison to students who received instruction through the traditional LA, those who used CM demonstrated a significant improvement in their ability to solve analytical chemistry problems and had a deeper understanding of the subject. This finding supports the research conducted by Taber and García-Franco [14], who found that students taught through CM performed better on exams and demonstrated a deeper understanding of physical chemistry concepts than students taught through traditional LA.

According to the study's findings, students who received their chemistry instruction through CB scored noticeably higher than those who received instruction via the traditional LA. This observation can be explained by the fact that CB helps students develop their capacity for critical thought and problem-solving. Furthermore, students may be more likely to remember the information over time and perform better if they actively engage with the subject and draw connections between various concepts. This study supports the findings of Ates and Aktamis [19], who found that students who participated in CB exercises showed higher creativity and problem-solving abilities than their non-participating peers. Similarly, a study by Yang *et al*. [20] found that students taught through CB performed better on tests that measured analytical reasoning and critical thinking than those taught through the traditional LA. Additionally, according to the study, the average achievement scores of male and female students who received CM instruction in chemistry did not differ statistically significantly. Students who learned chemistry using CM, both male and female, scored similarly. The equal participation of both sexes may explain this outcome. Both male and female students enthusiastically participated in the CM activities, offering equal learning and participation opportunities. The results of Iyekekpolor *et al*. [12] who noted different effects of CM on the academic achievement of male and female students in chemistry, conflict with this conclusion. The researchers found that CM exercises benefitted students of both genders. This finding also disagrees with Tsaousis and Alghamdi [26] who reported that female students engaged in CM activities performed better in assessments than their male counterparts, and Mwihia [27], who reported that male students performed better in assessments than their female counterparts.

The study showed again that there was no discernible difference between male and female students who received chemistry instruction through CB in terms of mean achievement scores. This is demonstrated by the equal participation of male and female students in the teaching process through CB. This finding supports the research of Olalere and Chado [28], who noted that male and female students who participated in CB activities significantly improved their understanding of organic chemistry concepts. This study demonstrates how CB, independent of gender, can raise students' chemistry achievement. However, this finding disagrees with that of Gaisey *et al*. [29] and Lesperance *et al*. [30] who reported although both genders improved their problem-solving abilities, females exhibited a higher level of engagement and motivation, leading to better overall achievement.

Some limitations or inadequacies exist in this study. To begin, the study relied on the students' normal chemistry teachers. The study results could have been impacted by the instructors' personality, lack of experience, attitude, and gender, which were not taken into account. It is important to note that the study only included 274 students from 6 schools. As a result, the study's conclusions may not be applicable to a wider context. To keep things going well for the cooperating schools, the curriculum was strictly adhered to, with no deviation from, the prescribed content. As a result of these limitations, it is recommended that similar research to cover more subjects be carried out to make for better generalization, study with longer time other than that used for the study to cover a wider content area, more schools, and greater number of subjects should be conducted, and a study of this type could be conducted using other variables like social and economic background, academic ability, attitude, and interest.

4. CONCLUSION

The study discovered that CM, as opposed to CB, had a significantly more considerable effect on students' achievement in chemistry. Chemistry achievement was substantially higher with CB than with the LA. The study found that, when compared to the LA, CM and CB are both more successful teaching strategies for raising students' achievement in chemistry. Additionally, it was discovered that CM was the most successful strategy. This is due to the fact that it makes chemistry content more dynamic, engaging for students, improving their comprehension and memory of the ideas. More so, students' gender did not affect how well CM and blending work. It was suggested that teachers of chemistry in secondary schools should adopt CM in teaching chemistry; school administrators organise seminars and workshops aimed at educating educators and learners on the integration and application of CM in chemistry instruction when CM is not an option, chemistry teachers should consider CB as a substitute teaching strategy.

To implement conceptual modeling in the existing curriculum, is to understand the problem domain, identifying important concepts and relationships, creating an initial model, assessing and improving the model, and documenting the finished model are the stages involved in putting CM into practice. Teachers of chemistry may face challenges when implementing CM in their lessons. The practical application of CM presents challenges. The modeller's degree of experience is one of these challenges. Additional reasons include the fact that some students learn the model rather than the illustrated concepts.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

Ethical principles were adhered to during the data collection process. The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author, [SO].

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