

Meta-Analysis of Studies on Effects of Instructional Approaches on Students' Academic Achievement in Chemistry

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Abstract: The focused on the meta-analysis of studies on effects of instructional approaches on students' academic achievement in chemistry. The study performed a meta-analysis of results from the experimental studies that examined the effect of teaching method/ strategies on academic achievement in chemistry, so as to arrive at the approach that had largest effect. size. Three research questions and five hypotheses guided this study. Ex post facto design was adopted for the study. Government owned universities in South East of Nigeria that offer chemistry in the Department of Science Education were used for the studies .The population of the study consisted of all unpublished previous studies on effect of teaching methods/ strategies on students' achievement in chemistry. A sample of 44 studies with 45 approaches carried out in Nigeria between 2000 to 2018 purposively drawn from four universities was used for this study. The random effects model was adopted. Descriptive statistics, statistical transformations and effect sizes were used to analyze the data for the research questions while the Winer combined test was used to test the hypotheses at 0.05 levels of significance. The findings of the study showed that the overall mean effect of instructional approaches on students' achievement in chemistry are respectively significant at 0.05 levels. The findings also revealed that meta-cognitive instructional strategies (MIS-0.730), computer Aided instruction (CAI-0.715), inquiry based teaching methods (IBTM-0.650), and cooperative learning (CL- 0.620) had large effect sizes but meta-cognitive instructional strategies (MIS) has the largest effect size on achievement. Based on the findings of the study, it was recommended among others that students in teacher training institutions and the already serving teachers should be trained in the approach of using metacognitive instructional strategies in teaching chemistry through seminars, workshops, conferences and in-service programmes.

Keywords: meta-analysis, effect size, achievement, chemistry, instructional approach

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I. Introduction

Chemistry is one of disciplines through which the educational objectives are to be achieved. It is the science that systematically studies composition, properties and activities of organic and inorganic substances and various elementary forms of matter (Nnoli, 2011). Chemistry plays a vital role in the future progress of mankind and nation. According to the Nigerian Educational Research and Development Council (NERDC, 2007), it is very important for effective living in modern age of science and technology. Given its application in industries, and in many other professions, the minimum standard embodied in chemistry education is designed to build confidence in students and enhance their abilities to adapt to the changing situation in scientific and technologically oriented society. Based on these important issues, students are expected to manifest high level of achievement in the subject yet, Onwukwe (2011) noted that students do not achieve well as they should in chemistry.

Researchers however, have been undaunted in their quest to finding a lasting solution to the problem. These effort led the researchers to investigate various teaching methods/ strategies on students academic achievement to determine the methods that enhance achievement most. Notwithstanding various findings and recommendations given by researchers, chemistry teachers have not found it easy to select and apply most effective teaching method for success of their students because most of the methods experimented upon proved to be significant and some not statistically significant. Additionally, their significance varied in magnitude and direction that one cannot easily say the degree of their effectiveness. Example, studies on guided inquiry by Odukwe (2018), concept mapping by Ikokwu (2015), self-regulated learning by Loong (2016), computer assisted instruction by Okwuduba (2016), cooperative learning by Izuegbuna(2018) among others indicated significant effects on students' achievement .

These researchers' reports show some conflicting results in magnitude and direction in their effect size. Even, findings from replications of studies show some inconsistencies. The most distressing thing is that one cannot categorically state the extent of the effect of each teaching method in enhancing students' interest

and achievement or state the method with greatest effect size that holds great promise in enhancing students' achievement. Thus, the possible way to arrive at a consensus on the method with greater effect is through integration of the previous studies results so as to provide a composite view of the mean effect size of teaching approaches on interest and achievement in chemistry. However, it may not be easy to integrate all studies especially when varieties of statistical tools have been used but, Bryce (2005) found meta-analysis as the quantitative review that can focus on integration of multiple studies.

Meta-analysis according to Cheung (2014) is a statistical analysis which combines or integrates the results of several independent studies considered by the analyst to be combinable. It is also a collection of systematic techniques for resolving apparent contradictions in research findings; A meta-analysis on a given research topic is directed toward the quantitative integration of findings from various studies, where each study serves as the unit of analysis. In a meta-analysis, studies are collected, coded and interpreted using statistical methods similar to those used in primary data analysis. Meta-analysis uses effect size as a metric for judging the magnitude of the standardized difference between a treatment and control condition in a large set of studies and may also be used to judge the magnitude of the relationship (r^2 or r^2) between measured variables in a large set of studies (Leandro,2005). Effect size is a name given to a family of indices that measure the magnitude of a treatment effect. Rosenthal (1984) defined it as estimate of the magnitude of the relationship between two or more variables. In the present study, effect size is used to measure the strength of the relationship between the instructional approaches investigated by researchers.

Instructional method is defined as a way or systematic process employed by teachers in a bid to facilitate learning. It is a path followed in communicating knowledge to the learner by the teacher with the view of securing the best individual result (Harbor-Peters, 2001). It has to do with the manner in which knowledge, skills and values are transmitted to the learners. Strategies on the hand can be seen as sequence of moves or procedures involved in the teaching of a concept. Harbor-Peters (2001) saw strategies as approaches of averting aversion in teaching of school. In the context of this study, strategies, techniques, and method, were used interchangeably to connote instructional approaches. Methods/strategies enumerated are very important and crucial factors in enhancing students' academic achievement in chemistry.

Academic achievement is a degree of attainment of students in task or successful accomplishment of program to which they were efficiently exposed to. Daniels and Mekonnen (2014) defined academic achievement as the scholastic standing of a students at a given moment as explained in terms of the grades and performance on an educational achievement test and cumulative indicators such as educational degree and certificates. Students' academic achievement could be improved when the method adopted by the teacher suits their developmental levels and creates room for active participation (Mbah&Leghara, 2008). Thus, the studies of the combined effects of all the appropriate instructional approaches used by researchers, need to be investigated using meta-analytical approach. Attempts made at integrating research studies through meta-analytic procedure thus far have focused on mathematics and sciences subjects generally and most of them were did not include majority of the recent studies. The necessity of the present study is therefore, a worthwhile quest.

II. Purpose Of The Study

The purpose of this study is to determine the instructional approach that has the largest effect size on students' achievement in chemistry. Specifically, the study determined:

1. the magnitude of the effect size of each of the studies examined on instructional approaches on students' Academic achievement in Chemistry.
2. the effect size for each of the studies examined on the effect of instructional approaches on achievement.
3. the overall mean effect size for all the studies examined on students' academic achievement.

III. Research Questions

The following research questions guided the study.

- 1 What is the magnitude of the effect size of each of the studies examined on effect of instructional approaches on students' achievement in chemistry?
- 2 What is the mean effect size for each of the studies examined on the effect of instructional approaches on students' achievement in chemistry?
- 3 What is the overall mean effect size for all the studies examined on the effect of instructional approaches on students' achievement in chemistry?

IV. Hypotheses

The following hypotheses were tested at 0.05 level of significance:

1. The overall mean effect size of meta-cognitive instructional strategies (MIS) on students' academic achievement in chemistry is not statistically significant

2. The overall mean effect size of computer assisted instruction (CAI) on students' academic achievement in chemistry is no statistically significant
3. The overall mean effect size of inquiry based teaching method (IBTM) on students' academic achievement in chemistry is no statistically significant
4. The mean effect size of cooperative learning (CL) on students' academic achievement in chemistry is no statistically significant
5. The overall mean effect size of all instructional approaches on students' academic achievement in chemistry is no statistically significant

V. Method

The study adopted ex-post facto research design. The population of this study consists of all research studies (example master's and doctoral thesis/dissertation) on effect of instructional approaches on students' academic achievement in chemistry conducted in Nigeria that are done in the universities in South East between 2000 and 2018. The total estimated population was 109 studies. The sample for the study consists of 44 research studies with 45 instructional approaches on students' academic achievement in chemistry. These studies were drawn from four (4) universities out of nine universities that offer courses in science education or Education Foundations, Four universities were chosen because some universities do not have such studies in their library and some have not graduated students in post graduate studies as at the time researcher visited. Purposive and random sampling techniques were used in drawing the studies that constituted the sample. To be included in the review, the studies had to meet the following criteria: the study should examine the effect of instructional approaches on students' academic achievement in Chemistry. The study should fall under metacognitive strategy, computer assisted instruction, inquiry based teaching method and cooperative learning; the study must be conducted in Nigeria between 2000 and 2018 and it must be tested on secondary school level chemistry subject; the study should be an experimental research, comparing a treatment (experimental) group with control groups whose outcome variable was a measure of students' academic achievement and interest in chemistry; the study should provide sufficient statistical data (N, \bar{x} , SD among other) to allow for the calculation of effect sizes.

Coding sheet was used to obtain the features of the studies. It was to ensure that all the information required from the various studies were recorded and examined in a consistent/ the same way. The instrument was adapted from Woodward(2006). The coding sheet consists of items listed in a tabular form making up sections showing the following: serial number of the study, author (s) of the study, year of study, type of study, type of the study, secondary school level of students, sample size, , teaching method/strategy, category of teaching method/strategy, type of instrument, indicator measured, Statistical method used, result of analysis, significance of test and effect size of studies examined. Lastly effect sizes as common measures of study outcomes; and search for relationships between study features and study outcomes will be calculated. The instrument was validated by three specialist; two in Educational measurement and Evaluation in University of Nigeria, Nsukka and one in Science Education, NnamdiAzikiwe University, Awka. Twelve (12) studies were given to two people (called rater X and Y) in Science education (measurement and Evaluation) in University of Nigeria, Nsukka to read independently, and make their rating. Based on the outcome of their rating, the reliability of instrument was calculated using the formula inter-rater agreement which yielded a coefficient of 0.95.

First of all, the researcher went to the universities libraries of the universities sampled and obtained previous studies on the effect of teaching approaches on students' academic achievement and interest in chemistry. Relevant studies were collected, abstract, chapter 3 and four of each thesis were photocopied. Secondly, the characteristics of those studies were coded using the coding sheet. The researcher converted the t vale to F-value so that all were uniform because most of studies gathered reported with F-ratio as their test statistic. Descriptive statistics (percentage, mean and standard deviation), statistical transformations, effect sizes and Winer Combined Test Approach were used to analyze the data collected. From the effect size of individual studies, the mean effect size for all the studies on students' achievement was determined. In order to categorize the magnitude of the effect size into large, medium or small, the effect sizes obtained were analyzed and categorized based on Cohen's (1977) guideline, that is: Effect size $r \leq 0.2$ represents small effect, $0.2 < r \leq 0.5$ represents medium and $r > 0.5$ represents large. Winer combined test method was used to test the null hypotheses at 0.05 levels of significance.

VI. Result

Research question 1: What is the magnitude of the effect size of each of the studies examined on effect of instructional approaches on students' achievement in chemistry?

Table 1: Magnitude of Effect size on Studies Examined on effect of Instructional approaches on Students' Academic Achievement in Chemistry

Statistical Method used	Total No of Studies	Quality of Effect Size	Categories of Teaching Method				Total	Percentage
			MIS	CAI	IBTM	CL		
Mean and SD	44	Large	08	12	06	04	30	66.67
ANCOVA	33	Medium	03	01	03	nil	07	15.56
MANOVA	02	Small	03	03	01	01	08	17.77
ANOVA	03							
Z-test	01							
t-test	05							
Total	45		14	16	10	05	45	100.00

NB: Effect size $r < 0.2$ –small; $0.2 < r \leq 0.5$ - medium; $0.5 < r \leq 0.8$ – large effect size

Table 1 shows that out of the 45 studies examined on effect of instructional approaches on achievement, all the studies used mean and Standard deviation to answer their research questions, 33 used analysis of covariance (ANCOVA) to test their hypotheses, 02 used multiple analysis of variance (MANOVA), 03 used analysis of variance (ANOVA), 01 used z-test and 05 used t-test to test their hypotheses. This shows that majority of the studies (73.33%) used ANCOVA to test their hypotheses. Similarly, 30 studies (66.67%) examined reported large effect size, 07 of the studies (15.56%) reported medium effect size, and 08 of the studies (17.77%) reported small effect size. This implies that majority of the study have large effect size on achievement.

Research question 2: What is the mean effect size for each of the studies examined on the effect of instructional approaches on students' achievement in chemistry?

Table 2: Mean effect size of each of the studies examined on effect of instructional approaches on achievement

S/N	Approaches	No of Studies	$\sum (N-3)$	$\sum (\text{Weighted } Z)$	Average Z $= \frac{\sum \text{weighted } Z}{\sum (N-3)}$	r value of Average z	Percentage (100r ²)
1	MIS	14	1862	1004.677	0.9396	0.730	53.29
2	CAI	16	1840	1646.08	0.89446	0.715	51.12
3	IBTM	10	1595	1243.638	0.7797	0.650	42.25
4	CL	5	488	355.869	0.7293	0.620	38.44

NB: Effect size $r < 0.2$ –small; $0.2 < r \leq 0.5$ - medium; $0.5 < r \leq 0.8$ – large effect size

Table 2 shows that the mean effect sizes for meta-cognitive instructional strategies (MIS), Computer Aided instruction (CAI), inquiry based teaching methods, and Cooperative learning (CL) approach on students' achievement are: 0.73, 0.72, 0.65, and 0.62 respectively. This means that meta-cognitive instructional strategies (MIS), computer Aided instruction (CAI), inquiry based teaching methods, and cooperative learning (CL) have large effect sizes on students' achievement, however, meta-cognitive instructional strategies (MIS) has the highest large effect size followed by computer Aided instruction (CAI). The table, equally shows that meta-cognitive instructional strategies (MIS), and computer Aided instruction (CAI) have high percentage variance (53.29 and 51.12) on achievement of students in Chemistry.

Research question 3: What is the overall mean effect size for all the studies examined on the effect of instructional approaches on students' achievement in chemistry?

Table 3: Overall mean effect size for all the studies examined on effect of instructional approaches on students' achievement in chemistry

Method/Strategy	No of Studies	$\sum (N-3)$	$\sum (\text{Weighted } Z)$	Average Z $= \frac{\sum \text{weighted } Z}{\sum (N-3)}$	r value of Average z	Percentage (100r ²)
Overall	45	5785	4250.291	0.7347	0.625	39.06

Table 3 reveals a large effect size (0.625) of all the studies examined under instructional approaches on students' achievement in chemistry. This suggests that all the instructional approaches examined have large effect size on students' achievement in Chemistry. The table also, shows percentage variance (39.06%) in

students' achievement that can be attributed to instructional approaches. This means that there are other variables (60.94%) outside instructional approaches that affect students' achievement.

Hypothesis 1: The overall mean effect size of meta-cognitive instructional strategies (MIS) on students' academic achievement in chemistry is not statistically significant.

Table 5: Winner Combined Test on overall effect of meta-cognitive instructional strategies (MIS) on students' academic achievement in Chemistry

Σt	Σdf	$\Sigma df-2$	$\Sigma df/df-2$	Z-cal.	Z-critical	Decision
70.973	2139	2111	14.2474	18.802	1.96	Sig.

Table 5 shows calculated Z score of 18.802 and critical z value of 1.96. Since the critical value is less than the calculated value, the null hypothesis was rejected and the alternative hypothesis upheld. This means that the overall effect of meta-cognitive instructional strategies (MIS) on students' academic achievement in chemistry is statistically significant.

Hypothesis 2: The overall mean effect size of computer assisted instruction (CAI) on students' academic achievement in chemistry is not statistically significant

Table 6: Winner Combined Test on overall effect of computer assisted instruction (CAI) on students' academic achievement in Chemistry

Σt	Σdf	$\Sigma df-2$	$\Sigma df/df-2$	Z-cal.	Z-critical	Decision
120.411	1856	1824	16.3364	29.791	1.96	Sig.

Table 6 reveals calculated Z score of 29.791 for CAI and critical z value of 1.96. Since the critical value is less than the calculated value, the null hypothesis was rejected and the alternative hypothesis upheld. This means that the overall effect of computer assisted instruction (CAI) on students' academic achievement in chemistry is statistically significant.

Hypothesis 3: The overall mean effect size of inquiry based teaching method (IBTM) on students' academic achievement in chemistry is not statistically significant

Table 7: Winner Combined Test on overall effect of inquiry based teaching method on students' academic achievement in Chemistry

Σt	Σdf	$\Sigma df-2$	$\Sigma df/df-2$	Z-cal.	Z-critical	Decision
63.625	1605	1585	10.157	19.964	1.96	Sig.

Table 7 reveals calculated Z score of 19.964 and critical z value of 1.96. Since the critical value is less than the calculated value, the null hypothesis was rejected and the alternative hypothesis upheld. This means that the overall effect of inquiry based teaching method (IBTM) on students' academic achievement in chemistry is statistically significant.

Hypothesis 4: The mean effect size of cooperative learning (CL) on students' academic achievement in chemistry is not statistically significant

Table 8: Winner Combined Test on overall effect of cooperative learning (CL) on students' academic achievement in Chemistry

Σt	Σdf	$\Sigma df-2$	$\Sigma df/df-2$	Z-cal.	Z-critical	Decision
23.936	493	483	5.106	10.592	1.96	Sig.

Table 8 shows calculated Z score of 10.592 and critical z value of 1.96. Since the critical value is less than the calculated value, the null hypothesis was rejected and the alternative hypothesis upheld. This means that the overall effect of cooperative learning (CL) on students' academic achievement in chemistry is statistically significant.

Hypothesis 5: The overall mean effect size of instructional approaches on students' academic achievement in chemistry is not statistically significant

Table 9: Winner Combined Test on overall effect of instructional approaches on students' academic achievement in Chemistry

Σt	Σdf	$\Sigma df-2$	$\Sigma df/df-2$	Z-cal.	Z-critical	Decision
278.944	6093	6003	45.847	41.197	1.96	Sig.

Table reveals calculated Z score of 41.197 and critical z value of 1.96. Since the critical value is less than the calculated value, the null hypothesis was rejected and the alternative hypothesis upheld. This means that the overall effect of instructional approaches on students' academic achievement in chemistry is statistically significant.

VII. Discussion

Findings showed that majority of the studies 30(66.67%) examined on effect of instructional approaches have large effect size while 7(15.56%) have medium effect and 8(17.77%) have small effect sizes on achievement. Findings of the study also revealed that meta-cognitive instructional strategies (MIS), computer Aided instruction (CAI), inquiry based teaching methods, and cooperative learning (CL) all have large effect size on students' achievement, however, meta-cognitive instructional strategies (MIS) has the highest large effect size followed by computer Aided instruction (CAI). The highest effect size by met cognitive instructional strategies could be as a result of self- planning, self monitoring, self evaluation and remedial activities provided by MIS which give the students opportunity to master the chemistry concepts without much difficult. This result agrees with finding of Ogbonna (2014).who asserts that MIS had a significant positive effect on promoting both students' achievement and interest in chemistry when compared to the conventional instruction. Furthermore, MIS provide effective scaffolds to learners to engage in scientific reasoning so as to generate meaning, connect instances and concepts, integrate conceptual understanding etc and then to access appropriate scientific knowledge and be able to use them in new situation. Findings also, showed that meta-cognitive instructional strategies (MIS), and computer Aided instruction (CAI) have high percentage variance (53.29 and 51.12) on achievement of students in Chemistry. This finding could be attributed to interactive and students' involving nature of the approaches.. . Meta-cognitive instructional strategies for example make students to reason/think and solve problems by themselves. On the other hand, computer aided instruction arouses curiosity, and interest of the students by virtue of its interesting features like animation which is captivating. CAI presents concepts with pictorial illustration. The pictorial illustration were considered effective in enhancing achievement in science for both concrete, operational and formal operational. According to Okwuduba (2016), the use of CAI in teaching creates multi Sensory channel for learning and this usually enhances learning since students tend to learn more and better when more these senses are involve than one sense. All these could be the reasons behind the large effect size they have.

Findings, also showed that the overall effect size of meta-cognitive instructional strategies (MIS), computer assisted instruction (CAI), inquiry based teaching methods (IBTM), and cooperative learning (CL) on students' academic achievement in Chemistry are statistically significant. Meaning that the overall effect sizes of all instructional approaches on students' academic achievement in Chemistry is statistically significant.

Findings of the study agreed with the findings of Ugwuanyi (2015) who found cooperative learning method having the largest effect size on students' achievement, Findings of the study also, agreed with the findings of Eya (2014) who found that out of the 138 studies investigated, majority of the studies have large effect size on achievement. The findings of the study also agreed with the findings of Sedat (2016) who carried out a meta-analytical on the effect of instructional designs based on the learning styles models on academic achievement, attitude and retention and found that instructional designs based on the learning styles model had a large effect on the academic achievement($d = 1.029$), attitude ($d = 1.113$) and retention ($d = 1.290$). The findings also agreed with the findings of Mustafa (2010) who found that computer assisted instruction has more effect than traditional teaching.

However, the findings contradicts the findings of Ugbaja (2012) who reviewed 36 research studies on the effects of instructional methods/strategies on students' achievement in science using meta-analysis procedure and revealed that the mean effect size of instructional methods on students' achievement in biology was moderate and that of chemistry, mathematics and physics were small. the difference in findings could be as a result of different methods of data analysis used by the two studies. Findings also, disagreed with the findings of Kadivar, Manzari and Sarani (2012) who found moderate effect size ($r=0.41$) of cognitive strategies and metacognitive strategies ($r=0.29$) and overall ($r=0.38$). This difference in the findings could be attributed to the ability of the researchers whose studies were meta-analyzed to control some extraneous variables of their study. It could also be attributed to the nature of the students used in the studies. If brighter students were used, it could give different results compared to using weak students.

VIII. Conclusion And Recommendation

It can be seen from the findings that the instructional approaches examined generally have positive and statistically significant effect on students' achievement in chemistry. This implies that when appropriate method such as metacognitive instructional strategy and computer-assisted instruction which has the largest effect size, is used in teaching and learning of chemistry, students' academic achievement will be improved. In the light of the findings of the study, it recommended that: meta-cognitive instructional strategies (MIS), computer Aided

instruction (CAI), inquiry based teaching methods, and cooperative learning (CL) should be adopted by science teachers in teaching science for enhanced academic achievement

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