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The Effects of Problem-Solving Instructional Strategy and Numerical Ability on Students' Learning Outcomes

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Abstract

The aim of this study was to examine the effects' of problem-solving instructional strategy and students' numerical ability on learning outcomes in chemistry.

A pre-test post-test control group quasi experimental design was adopted for the study. Data were collected from a sample of 210 SS2 Chemistry Students made up of 109 males and 101 females selected from six schools in three (3) Local Government Areas of Ekiti State, Nigeria based on multi-stage random sampling techniques. The Seven Step Chemistry Problem-Solving Model as suggested by Frazer (1981) and Selvarantnam (1983) was adopted for the study. The experiment was carried out on four (4) groups of Students. Students' in experimental groups 1, 2 and 3 were exposed to treatment (problem-solving approach) while the control group was taught using the conventional lecture method. The Numerical Ability Test (NAT) was administered on each of the four groups. Analysis of Covariance (ANCOVA) was used to analyse the data with the pre-test scores as covariates. The findings revealed that problem-solving instructional strategy as well as students' numerical ability improves performance in chemistry. Also, male and female students' of high and low ability levels do not differ in performance in chemistry at group levels. Based on findings, it was recommended that teachers should take note of the numerical ability levels of students' for effective lesson delivery in the teaching-learning situation.

Keywords: Problem-Solving, Numerical Ability, Learning Outcomes.

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I. INTRODUCTION

Within the last two decades, observation has shown that in spite of the various innovations introduced into science teaching in general and chemistry in particular, the performance of students still remains low. This is buttressed by the poor performance of students in the West African Senior School Certificate Examinations (WASSCE) (Adejumobi and Ivowi, 1992; Ezeudu, 1995).

Friedman (2000) also supported the idea that achievement in science is low and he attributed the reason for this among other things to the way Chemistry is taught by teachers with neither a major nor minor qualification in the subject. Several other reasons have been advanced for the under-achievement in Chemistry and other science subjects. Some of the reasons include; Poor Capital Investment in terms of provision of science resources (Agusiobo, 1998), Teachers' persistent use of traditional teaching methods which are ineffective in science pedagogy (Nworgu, 1997), Perceived difficult nature of topics in Chemistry by students (Onwu, 1993 and Ogbonnia, 1999), Poor computational skills, inability to apply learned concept, principles, formulae, units and lack of procedural guide or problem-solving skills (Bellow, 2005).

Furthermore, the importance of mathematics in the studying and understanding of science has been recognized worldwide. Salau (2000) points out that there exists a link between mathematics and other science subjects. The finding of Daniel as quoted in Osokoya (1999) was that a self-rating of Mathematics ability is a significant predictor of achievement in introductory college Chemistry. The research finding suggests that, there is a set of minimum mathematical skill necessary for passing Chemistry. Through the power of Mathematics, data collected in Chemistry can be used to predict the behaviour of matter. The ability to give both diagnostic as well as prognostic analyses of a physical phenomenon has made Chemistry the leading discipline in all the branches of science. In this work, the research into the effect of the mathematical ability of students on performance in Chemistry is considered as the research into the effect of students' numerical ability on performance in Chemistry.

Slightly related to students' perception of the nature of this subject is the issue of gender and achievement. Habor-Peters (1994) in his study on gender interaction on achievement discovered that there was a marked difference between the performance of male and female students. Oke (1995) and Joseph (1996) affirmed that boys performed better than girls in science. However, Tang (1989) found that gender difference is in favour of female students. Similarly, Toh's (1993) comparison in three practical problem-solving task indicated that girls distinctly preferred contents familiarity and out-performed boys in several process/skills when familiar with contents. This result therefore contradicted the general belief that boys performed better than girls in science related disciplines. On the other hand, Lagowski (1994) determined the effect of gender on problem-solving abilities in introductory Chemistry. The result showed no gender differences in some cognitive terms.

In recent time, the problem-solving approach has been advocated as one of the methods of teaching Chemistry. In the present study, an important model of instruction that can achieve the purpose of helping students' to learn and study chemistry effectively is the Seven-Step Chemistry Problem-Solving Model. It is designed to help students solve problems by proceeding in a logical step sequence from a problem state to a solution state. Thus, the student learn to define problem, collects information related to the solution of the problem and finally check and evaluate the solution obtained (Frazer, 1982 and Selvarantnam, 1983). Hence, the relative effects of problem-solving and students' numerical ability on students' learning outcomes in Chemistry using Seven Step Chemistry Problem-Solving Model was examined in this research.

Statement of the Problem

H_{O2}: The study seeks to determine the effects of problem-solving instructional strategy and students' numerical ability on learning outcomes (achievement and attitude) in Chemistry.

Hypotheses

H_{O2}: The following hypotheses were tested at 0.05 level of significance.

H_{O2}: There is no significant difference in the performance of students' taught Chemistry using problem-solving and those taught using the conventional lecture method of teaching Chemistry.

H_{O2}: There is no significant main effect of numerical ability on performance in Chemistry.

H_{O3}: There is no significant difference between the performance of students' in experimental and control groups in Chemistry Achievement Test (CAT) and Numerical Ability Test (NAT) respectively.

H_{O4}: There is no significant difference between the performance of male and female students' in Numerical Ability Test (NAT).

Methodology

Design: A pretest posttest control group quasi experimental design using 4x2x2 factorial design was used

O_1	X_1	O_2	O	(E_1)
O_3	X_2	O_4	O	(E_2)
O_5	X_3	O_6	O	(E_3)
O_7	X_4	O_8	O	(C)

where O_1, O_3, O_5, O_7 are pretest for the experimental and control groups respectively. O_2, O_4, O_6, O_8 are posttest for experimental and control groups respectively. O represents the Numerical Ability Test.

X_1 = SSCPSM with remediation
X_2 = SSCPSM with feedback
X_3 = SSCPSM with practice
X_4 = Conventional Lecture Method
SSCPSM = Seven Step Chemistry Problem-Solving Model.

Variables in the study

(a) Independent variable
(i) Problem-Solving Instructional Strategy
(ii) Numerical Ability (High and Low)
(b) Dependent variable

- Chemistry Achievement Test (CAT) Post-test

Population

All the Senior Secondary Class Two (SS2) Chemistry Students in Ekiti State, Nigeria constituted the target population for the study.

Schools and subjects

Senior Secondary Class Two (SS2) Chemistry Students from Six Schools were selected as sample for the study based on multistage random sampling technique. The six schools were selected based on the facts that the subjects had been taught the basic and prerequisite Chemistry concepts necessary for understanding of mole concepts, gas laws and solubility which were discussed in this work. All the 210 Chemistry Students which comprised 109 males and 101 females drawn from the six schools were participants in the study. Intact classes were used for the study.

Research Instruments

Two instruments and One Instructional package were used for the study. They are:

1. **The Chemistry Achievement Test (CAT)**

This is made up of fifty (50) four options multiple choice items based on the topics treated in the study (i.e. gas laws, mole concept and solubility) used for the study. The CAT was designed to measure students' achievement (learning outcomes) in Chemistry. Experts in the field of Science Education validated the CAT in terms of ensuring items clarity and removal of ambiguous words that could confuse the students. The reliability co-efficient obtained for CAT using the test re-test method was 0.75.

2. **The Numerical Ability Test (NAT)**

This was designed to test the mathematical knowledge of the students. It is made up of forty (40) five options multiple choice items based on the topics in mathematics which is related to the academic level of the learner. Experts in the field of Mathematics Education and Test Construction subjected the NAT to face and content validity. The reliability co-efficient obtained for NAT was 0.71.

- **Instructional Package**

Nine Teaching manuals were used for treatment in the study. Four of the teaching manuals were taught for 40 minutes each while the rest were taught for 80 minutes (i.e. Double Period) lesson period. The Experimental Groups were taught using the Seven Step Chemistry Problem-Solving Model (SSCPSM) with varying modes of instruction earlier specified while the Control Group was taught using the Conventional Lecture Method.

Procedure for data collection

The procedure for data collection was in three main phases and it lasted for seven weeks. The phases were:
Pre-test for the first one week
Treatment for the next five weeks
Post-test for the last one week of the seven weeks
Prior to the collection of data, the participating teachers and students were trained. The training programme lasted for two weeks. The training of the teachers and students focused on the use of (SSCPSM) and the different treatment conditions. The teachers and the students in the control group were not given any special training.

Pre-test

The instruments were administered in the following order: the chemistry achievement test on students' followed by the students' numerical (mathematical) knowledge test.

Treatment

Experimental Group

Treatment in this group involved the following steps.
- Teachers presented the topic in form of discussion with the demonstration of the how to solve given problems using the SSCPSM for Students based on Groups.
- Students in Experimental Group 1 were made to solve given problems using the SSCPSM while the Teacher remediates the work of each student in the group.
- Students in Experimental Group 2 were also given problems to be solved using the SSCPSM while the Teacher provides the feedback of the work to each student in the group.
- Students in Experimental Group 3 were asked to practice solving given problems using the SSCPSM.
- Teachers recognized the performance of the Students in each of the Group.
- Teachers gave assignment

Control Group

The treatment for each lesson involved the following steps:

- The teacher presented the topic in form of lecture.
- Students listened to the teacher and wrote down the chalkboard summary.
- Students asked the teacher questions on areas of the topic that is not clear to them.
- The teacher also asked the students questions and the students responded accordingly.
- Students were given problems to be solved while the Teacher marked to assess their performance.

Post-test

After seven weeks of treatment, the CAT- whose items had been re-arranged was administered as the post-test on the experimental and the control groups. The NAT was re-administered again.

Data Analysis

Analysis of Covariance (ANCOVA) was used to analyse the data. Scheffe's Pairwise comparison was also used to establish the variation due to treatment and to locate the source of significance.

Table 1:- Summary of ANCOVA of pre-test and post-test scores of the Problem-Solving groups and Control group.

Source	SS	Df	MS	F_{cal}	F_{tab}
Covariate (pre- test)	7102.29	1	7102.29	3010.59	3.84
Main effects:					
Treatment	854.55	3	284.85	120.75	2.60
Explained	8282.88	4	2070.72	877.76	2.37
Residual	8766.49	209			
Total	202354.00	210			

$P > 0.05$

Table 1 shows that the F_{cal} value (120.75) was greater than F_{tab} value (2.60) at 0.05 level of significance. Therefore the null hypothesis was rejected. This shows that there was a significant difference in the academic performance of those students exposed to problem-solving instructional strategy and those in the control group. Hence, one can infer from above that the problem-solving approach has aided the groups to achieve better performance compared to their counterparts taught with the conventional lecture method.

In order to determine the pairwise difference among the groups, Scheffe's (Post-Hoc) Analysis was used; the result is presented in Table 9 below.

Table 2:- Post-Hoc Analysis Showing the Effect of Problem-Solving on Students' Performance in Chemistry.

Groups	E_1	E_2		C	N	Mean
Problem-solving coupled with Remediation (E_1)		*		*	70	33.56
Problem-solving coupled with Feedback (E_2)					70	30.26
Problem-solving coupled with Practice (E_3)					35	28.41
Control (C)					35	27.97

*The mean difference is significant at 0.05 level.

Table 2 shows that there was a significant difference between the performance scores of students in Experimental Group 1 and Experimental Group 2. Similarly, the mean difference between Experimental Group 1 and control group is statistically significant at 0.05 level.

Table 3:- Summary of ANCOVA on Pre- test and Post- test Scores of the Experimental (problem- solving) Groups and the Control group in the Numerical Ability Test (NAT)

Source	SS	Df	MS	F_{cal}	F_{tab}
Covariate (pre- test)	7325.31	1	7325.31	1139.11	3.84
Main effects:					
Ability	6.99	1	6.99	1.09	3.84
Explained	7435.33	2	3717.66	578.11	3.00
Residual	8766.50	209			
Total	202354.00	210			

$P < 0.05$

Table 3 shows that F_{cal} (1.09) was lower than F_{table} (3.84) at 0.05 level of significance. The null hypothesis was therefore accepted. This implies that there is no significant effect of students' numerical ability on performance in Chemistry.

It could be deduced from the above that the numerical ability level of students in Chemistry is not a perfect predictor of their performance in Chemistry; as high and low ability students could have improved performance in Chemistry depending on the method of teaching adopted in the teaching-learning process.

Table 4:- Summary of ANCOVA on the Pre- test, Post- test Scores of students in the Chemistry Achievement Test (CAT) and Numerical Ability Test (NAT) based on groups.

Source	SS	Df	MS	F_{cal}	F_{tab}
Covariate (pre- test)	6693.23	1	6693.27	2871.55	3.84
Main effects:					
Ability	6.77	1	6.77	2.91	3.84
Group	849.31	3	283.10	121.46	2.60
2-Way Interactions					
Ability * Group	7.98	3	2.66	1.14	2.60
Explained	8297.99	8	1037.25	445.00	1.94
Residual	8766.50	209			
Total	202354.00	210			

$P < 0.05$

Table 4 shows that F_{cal} (1.14) was less than F_{table} (2.60) at 0.05 level of significance. The null hypothesis was therefore accepted. From the analysis above, it could be inferred that there was no significant difference between the performance of students in the Chemistry Achievement Test and Numerical Ability Test based on groups.

Table 5:- Summary of ANCOVA on the pre- test, post-test scores of male and female students in Numerical Ability Test (NAT) based on groups.

Source	SS	Df	MS	F_{cal}	F_{tab}
Covariate (pre- test)	4298.55	1	4298.55	1793.97	3.84
Main effects:					
Ability	6.21	1	6.21	2.59	5.99
Sex	2.50	1	2.50	1.04	10.10
Treatment	842.33	3	280.78	117.18	2.60
2-Way Interactions:					
Ability * Sex	0.39	1	0.39	0.16	0.16
Ability * Group	7.63	3	2.55	1.06	4.07
Sex * Group	3.12	3	1.04	0.44	9.28
3- Way Interactions:					
Ability * Sex * Group	0.26	3	0.09	0.04	0.22
Explained	8304.05	16	519.00	216.60	1.67
Residual	8766.50	209			
Total	202354.00	210			

$P < 0.05$

Table 5 shows that F_{cal} (0.04) was less than $F_{tab.}$ (0.22) at 0.05 level of significance. The null hypothesis was therefore accepted. This implies that there was no significant difference between the performance of male and female students in the Numerical Ability Test based on groups. The deduction that could be made from above is such that male and female students of high and low ability levels do not differ in performance in Chemistry at the group levels.

Discussion of Findings

Findings from the results of all the seven hypotheses tested showed convincingly that the problem- solving approach proved to be a more effective and reliable method of teaching than the conventional lecture method**.** This finding provided empirical support to earlier findings: Bodner (2000) and Domin et- al (2001) which remarked that there is significant improvement in students' achievement when problem-solving is accompanied with corrective measures such as verbal feedback and teacher-directed remedial instruction. Other empirical studies which gave positive effects of problem-solving models on achievement in other science subjects includes Martin and Oyebanji (2000), Decorte and Scriners (2002), Payne (2004).

The study also showed that the students with high numerical ability performed better than their low numerical ability counterparts across the four groups in Chemistry. This is in agreement with the findings of Benbow (1992), Inyang and Ekpeyong (2000). The result is however contrary to the findings of Fisher (1996) who found out that numerical ability shows no relationship to Chemistry achievement. This study also reflected that male and female students of high ability levels across the four groups performed better than their low ability level counterparts. This finding was opposed by Navarro (1989), who posited that there is correlation between gender difference and the performance of students of high and low ability levels in a Mathematics Scholastic Aptitude Test (SAT).

Conclusion and Recommendation

The major conclusion that could be drawn from the study based on the performance of students is that the conventional lecture method of teaching Chemistry proved less effective than the problem-solving method. In addition, the incorporation of problem-solving into Chemistry learning improves the performance of students with high ability than their counterparts with low ability.

If problem-solving instructional strategy could improve students' learning outcomes in Chemistry, it would be necessary to overhaul the mode of instruction of teaching Chemistry at the Senior Secondary so as to accommodate functional student–centred and activity-oriented instructional strategy that will make Chemistry students good problem-solvers, thereby causing improvement in the performance of students in School Certificate Chemistry Examinations thereby replacing the Conventional Lecture Method (i.e Chalk and Talk Method) of teaching Chemistry in Schools. Also, Secondary School teachers who are already in service should be given adequate training through workshops, symposia, conferences and seminars to enhance and acquire better strategies of teaching Chemistry. Schools' Curriculum should be overhauled to accommodate problem- solving and activity-oriented instructional strategies.

Teachers should take into consideration the numerical ability of students in the teaching-learning process for effective delivery of their lessons with a view to improving the performance of students in Chemistry.

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