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Effectiveness Of A Transfer-Enhancing Instructional Method For Teaching A Mathematical Concept On Students' Computational Skill In Volumetric Analysis

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Abstract
This study investigated the effectiveness of a transfer-enhancing instructional method for teaching a mathematical concept, ratio and proportion, as prerequisite mathematical concepts, on students' computational skills in volumetric analysis in Chemistry. A total of 105 Senior Secondary I (SS1) students, randomly selected from three selected schools in the existing three senatorial zones in Osun State, Nigeria, participated in the study. The students were divided into two experimental groups and a control group. Experimental Group 1 was taught ratio and proportion using the Conventional method of teaching, Group 2 was taught using the 'Mathematics as a Language of Science' approach while the control group was not exposed to the teaching in the ratio and proportion concept. The results of the data analysis revealed that students who were taught ratio and proportion using the 'Mathematics as a Language of Science' approach performed significantly better in the computational aspects of volumetric analysis than those who were not taught these prerequisite concepts. Furthermore, students taught using the Mathematics as a Language of Science approach performed significantly better than those taught using the Conventional method of instruction. Based on these findings, it was concluded that prior knowledge of ratio and proportion enhances students' computational skills in volumetric analysis. Additionally, teaching mathematical concepts in direct relation to their application in science promotes better understanding and knowledge transfer. The study therefore established that the Mathematics as a Language of Science approach is more effective for teaching prerequisite mathematical concepts in a way that supports learning in related science topics than the conventional method of instruction. It was recommended, among others, that relevant mathematical prerequisites should be adequately taught and mastered before introducing related science concepts.

Keywords: *Instructional Methods, Mathematical Concept, Computational Skill, Volumetric Analysis*

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I. Introduction

The role of science and technology in contemporary society cannot be overemphasized, as they are central to addressing fundamental human needs such as healthcare, food production, clean water, energy, and education. In addition, advancements in science and technology continue to drive improvements in transportation, communication systems, and industrial development. In developing countries such as Nigeria, there has been increasing emphasis on strengthening science education as a means of fostering technological growth and national development. Recent studies affirm that effective science education is critical for equipping learners with problem-solving skills and competencies needed in the 21st century (UNESCO, 2022; World Bank, 2023).

To achieve meaningful learning outcomes in science, there is a growing need to adopt effective and learner-centered instructional strategies. Traditional teaching methods, which often emphasize rote memorization and passive learning, have been shown to be less effective in promoting deep understanding of scientific concepts. Consequently, contemporary approaches such as inquiry-based learning, discovery learning, and activity-based instruction have been widely recommended. For instance, research has shown that inquiry-based teaching significantly enhances students' conceptual understanding and academic achievement in science compared to conventional lecture methods (Lazonder & Harmsen, 2021; Alfieri et al., 2022). Similarly, student-centered approaches that encourage active participation and self-directed learning have been found to improve retention and application of scientific knowledge (OECD, 2023).

However, it is important to note that the effectiveness of any teaching method may vary depending on the nature and complexity of the subject matter. In chemistry, particularly in volumetric analysis, students are required to perform quantitative reasoning involving calculations of concentration, volume, and mass relationships. These computations rely heavily on mathematical concepts, especially ratio and proportion.

Studies have indicated that students' difficulties in chemistry are often linked to weak mathematical foundations, particularly in proportional reasoning (Bicer et al., 2023; Ubuz & Yayan, 2022). This highlights the interdisciplinary nature of science learning and the need to integrate relevant mathematical skills into science instruction.

Ratio and proportion are fundamental mathematical concepts that underpin many chemical calculations, including molarity, dilution, and stoichiometric relationships. When students lack a solid understanding of these concepts, they tend to rely on memorization of formulas rather than conceptual reasoning, which negatively affects their computational skills and overall performance in volumetric analysis. Recent evidence suggests that explicit instruction and effective teaching strategies in ratio and proportion can significantly improve students' ability to solve quantitative problems in science (Risdiyanti et al., 2024; Copur-Gencturk et al., 2023).

In view of this, science educators have emphasized the need for teaching approaches that promote conceptual understanding and application of ratio and proportion in solving real-life and scientific problems. Rather than merely substituting values into formulas, students should be guided to develop problem-solving skills based on basic principles. Therefore, exploring effective instructional methods for teaching ratio and proportion is essential for improving students' computational competence in chemistry.

In realization of this need to explore viable instructional strategies for teaching ratio and proportion and other mathematics topics that would facilitate understanding science topics such as volumetric analysis studies have been conducted. For instance, research has shown that inquiry-based teaching significantly enhances students' conceptual understanding and academic achievement in science compared to conventional lecture methods (Lazonder & Harmsen, 2021; Alfieri et al., 2022). Nakakoji and Wilson (2020) advocated for teaching mathematics through problem-solving tasks combined with metacognitive strategies such as thinking-aloud reasoning, planning, and reflection. Others such as Adegoke and Folorunso (2023) found that the Mastery learning instructional technique enhanced conceptual mastering of mathematics topics and enhanced knowledge transfer. Kaldaras and Wieman (2025) also found that students exposed to integrated activities that required them **to** translate scientific phenomena into mathematical representations demonstrated strong short- and long-term transfer. They equally found that the approach improved students' ability to connect equations with real-world scientific observations.

However, to the best knowledge of this researcher, none of the studies specifically examined the effectiveness of a particular mathematical concept such as ratio and proportion on specific science concept such as volumetric analysis. The present study investigated the effect of a transfer-enhancing instructional method (the Mathematics as a Language of Science Method) for teaching ratio and proportion on the computational skills of Senior Secondary School I students in volumetric analysis.

Research Questions

The study attempted to answer the following questions:

(1) Will the performance in test of computational skill in volumetric analysis of students taught ratio and proportion using the Conventional Method differ from that of students not taught ratio and proportion?

(2) Will the performance in test of computational skill in volumetric analysis of students taught ratio and proportion using the Mathematics as a Language of Science approach differ from that of student not taught ratio and proportion?

(3) Will the ability to compute results of volumetric analysis of students taught ratio and proportion using Mathematics as a Language of Science approach differ from those taught using the Conventional Method?

Hypotheses

HO1: There is no significant difference between the computational skill in volumetric analysis of students taught ratio and proportion using the Conventional Method of instruction and that of those not taught ratio and proportion.

HO2: There is no significant difference between the computational skill in volumetric analysis of students taught ratio and proportion using the Mathematics as a Language of Science approach and that of those not taught ratio and proportion.

HO3: There is no significant difference between the computational skill in volumetric analysis of students taught ratio and proportion using the Conventional Method and that of those taught using the Mathematics as a Language of Science approach

II. Methodology

Sample and Sampling Procedure

A multi-stage sampling procedure was adopted. At the first stage, one secondary school was randomly selected from each of the three senatorial districts in Osun State and the three schools were randomly designated

Experimental group1, Experimental group2, and the control group. At the second stage one arm of senior secondary1 students was by a further process of simple random sampling selected from each school. At the third and final stage, a random sample of thirty-five students were selected from each of the three arms to obtain the sample size of one hundred and five SS1 students consisting of thirty-five (35) students for each of experimental group1, experimental group2 and control group.

Research Instruments

The major instruments developed for the purpose of the study were a:

(i) 25-items Ratio and Proportion Skill Test (RPST), and

(ii) 20-items Volumetric Analysis Performance Test (VAPT)

The Ratio and Proportion Skill Test (RPST) was a 25-item multiple choice tests. The questions were drawn from the areas of: expression of quantities as ratio in simplest form, finding the value of algebraic expressions given ratio in which the variables present are connected, finding the ratio in which three or more quantities are connected given ratios in which they are pairwise connected, sharing quantities in given ratio, direct and inverse proportion in everyday arithmetic, graph of direct and inverse relations, word problems involving direct and inverse proportion

The 20-item Volumetric Analysis Performance Test (VAPT) was also a multiple-choice test. The content areas include familiarization with titration apparatus such as pipette, burrette, acidic and basic solutions, and indicators (actual practicals were not carried out), meaning of terms such as burrette readings, end points etc. relating to titration, concentration of solutions, standard solutions, measuring concentration of solutions in terms of g/dm^3 and Molarity, calculations involving neutralization reactions – working from first principle using the knowledge of ratio and proportion to solve problems in which the formula = could be used, solving standard volumetric analysis problems including cases of calculating percentage purity of solutes.

The RPST was validated by giving the questions to two experts, one in the area of mathematics education, and the other in the area of test and measurements. Based on their comments some of the items were completely dropped while some were replaced to obtain the final set of twenty-five questions. The VAPT was similarly validated by giving the items to experts in the area of Chemistry education and tests and measurements. The two sets of questions were field tested in a school outside the study area. The results of the field tests were used to calculate the reliability coefficients of the RPST and VAPT as 0.79 and 0.82 respectively, using the Kuder-Richardson formula 21.

Data Collection Procedure

The teachers for the experimental groups were given copies of the content guides showing unit areas around which teaching in the two subjects were to be built. Using the content guides, the researcher took time to train the teachers on how to teach the contents.

The mathematics teachers in the experimental group 1 schools were taught how to use the Conventional Method. With this approach the students were to be taught the ratio and proportion topics in the traditional approach to teaching, the teachers were to refrain from drawing related examples and illustration from chemistry, particularly volumetric analysis. The mathematics teachers in the experimental group 2 were similarly trained on how to use the 'Mathematics as a Language of Science Approach'. Teachers of this schools was to incorporate examples and illustration drawn from volumetric analysis in chemistry as they teach the topic ratio and proportion. Teachers were guided on types of such examples and illustrations. Teachers used for this group were mostly first-degree holders in mathematics with sound chemistry background at a level above the ordinary level. Since the ratio and proportion topic would not be taught in the control school only the participating chemistry teachers were contacted.

On the first day of the six weeks the volumetric analysis performance test was administered to subjects in all the three schools as the pre-test. The experimental group I and 2 were taught ratio and proportion for the first three weeks according to the prescribed method for each group spending three hours each week. The control group were occupied by their normal school work during this period. The last three weeks were used for the teaching of volumetric analysis in all the three schools using the traditional method of instruction. At the last day of the experiment the volumetric analysis performance test was administered to the subjects in the three groups as the post -test. The scripts were collected, marked and record of scores kept along with the pre-test scores.

III. Results

The descriptive statistics of the students' scores in the Proportion Skill Test both before and after the teaching of the ratio and proportion topics are shown in table 1. The table shows that the two experimental groups benefited from the teaching with the experimental group2 having a mean gain score of 8.46 and experimental group1 7.46. Thus, attempting to relate any change in performance in the volumetric analysis later to the knowledge of the ratio and proportion would make sense.

Table 1: Descriptive Statistics of Performance in the Ratio and Proportion Skill Test

Group	N	Prior to Learning the Ratio and Proportion Concept		After Learning the Ratio and Proportion Concept		Mean Gain Score
		Mean	SD	Mean	SD	
Experimental Group1	35	3.80	1.208	11.26	1.146	7.46
Experimental Group 2	35	3.60	1.218	12.06	1.494	8.46
Total	70	3.70	1.208	11.66	1.382	7.96

The Analysis of Covariance (ANCOVA) was chosen as the main statistics for data analysis because it enables comparison of the posttest scores of the groups while controlling for the differences in the pretest.

However, the important basic assumptions of the ANCOVA were first of all tested to be sure that the assumptions were not violated. In particular, the assumptions of normality of the posttest scores, homogeneity of regression slope and homogeneity of variance were examined and the results presented in tables 2, 3 and 4.

Table 2: Test of Normality

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistics	Df	Sig	Statistics	Df	Sig
Posttest scores	.081*	105	.090	.985*	105	.297

Not significant $p > .05$

Table 3: Test of Homogeneity of Variance (Levene's Test of Equality of Error Variances)

Levene Statistic	F	df1	df2	Sig
.	1.393	2	102	.253*

Not significant, $p > 0.05$

Table 4: Test of Homogeneity of Regression Slope (Test of Between-Subject Effects)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	223.658	5	45.132	4.058	.002
Intercept	1668.269	1	1668.269	149/994	.000
Group	43.602	2	21.801	1.960	.146
Pretest	6.183	1	6.183	.556	.458
Group * Pretest	4.233	2	2.116	.190	.827
Error	1101.104	99	11.127		
Total	11727.000	105			
Corrected Total	1326.762	104			

*$R^2 = .170$ (Adjusted $R^2 = .128$) ** Not significant.

The Kolmogorov-Smirnov in Table2 shows that the normality condition was satisfied, $p = .090$, $p > .05$. The Levene's Test of Equality of Error Variances, table3, also shows that the condition for the homogeneity of variance was met, $F(2, 102) = 3.193$, $p > .05$). Table 4 further shows that the interaction between the covariate and the groups was not significant, $F(2, 102) = .190$, $p > .05$. That is, the regression lines showing relationship between the pretest and the posttest have the same slope across the three groups, thus showing that the assumption of homogeneity of regression slope was satisfied.

With the major assumptions of ANCOVA satisfied, the main ANCOVA was therefore run. The results are presented in tables 5 and 6.

Table 5: Descriptive and Adjusted (Estimated Marginal) Means of Posttest Scores by Group

Group	N	Descriptive		Adjusted	
		Mean	SD	Mean	Std. Error
Experimental Group1	35	9.51	3.293	9.508	.559
Experimental Group2	35	11.89	2.459	11.902	.560
Control	35	8.46	2.973	8.447	.559
Total	105	9.95	3.572		

Table 6: Test of Between-Subject Effects - ANCOVA

Source	Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Square
Corrected Model	221.425	3	73.808	6.744	.000	.169
Intercept	1685.692	1	1685.692	154.030	.000	.604
Pretest	5.634	1	5.634	.515	.475	.005

Group	218.751	2	109.376	9.994	.000	.165
Error	1105.337	101	10.944			
Total	11727.000	105				
Corrected Total	1326.762	104				

*R^2 = .167 (Adjusted R^2 = .142)

Table 5 shows both the descriptive and the adjusted statistics of the three groups in the quantitative analysis posttest. The table shows that experimental group2 has the highest descriptive/adjusted means among the three groups, with the control group having the least**.** The ANCOVA table 6 also shows that there was a significant effect of treatments on the posttest scores after controlling for the pretest performance, $F(2,102) = 9.994$, $p < .05$. To know the exact pairs of groups between which these differences exit the Bonferroni Post-hoc Test was carried out. the result is presented in table 7.

Table 7: Bonferroni Post-hoc Test for the ANCOVA

I Group	J Group	Mean Difference I – J	Std. Error	Sig
Experimental Group1	Experimental Group2	-2.394*	.791	.009
	Control Group	1.062*	.791	.547
Experimental Group2	Experimental Group1	2.394*	.791	.009
	Control Group	3.455*	.792	.000
Control Group	Experimental Group1	-1.082*	.791	.547
	Experimental Group2	-3.455*	.792	.000

*The mean difference is significant at .05 level

The Mathematics as a Language of Science method relates the teaching of mathematics content to relevant science topics during mathematics instruction while the Conventional method only teaches the usual way of traditional lecture method of teaching pure mathematics, refraining from drawing examples or extensive illustration from sciences and life situation. The table shows that there was no significant difference in the performance in the Volumetry Analysis of the group taught the ratio and proportion using the Conventional Method (Experimental group 1) and those not taught the ratio and proportion (control group). Therefore, the first null hypothesis, H_o1 was accepted. However, the group that was taught ratio and proportion using the 'Mathematics as a Language of Science' method (Experimental group 2) performed significantly better in the Volumetry Analysis than those not taught ratio and proportion (control group). Hence, the second null hypothesis H_02 was rejected. The group that was taught ratio and proportion using the 'Mathematics as a Language of Science' method (Experimental group 2) was also found to perform significantly better in the Volumetry Analysis than those taught the ratio and proportion using the Conventional method (Experimental group1). Hence, the null hypothesis H_03 was rejected.

IV. Discussion

The results revealed that students who learnt ratio and proportion prior to receiving instruction in the volumetric analysis performed better in the volumetric analysis than those who did not learn ratio and proportion. The difference was particularly statistically significant in the case of those who were taught the ratio and proportion using the Mathematics as a Language of Science approach although it was not statistically significant in the case of those taught the ratio and proportion by the Conventional Method. The implication of this finding was that students who learnt the necessary prerequisite knowledge to a new topic would have their understanding of the new topic remarkedly facilitated. That the difference by which the group taught the ratio and proportion by the Conventional Method was not significant might be a reflection of the known general weakness of the Traditional Method in which mathematics content are taught without relating the teaching to the relevant science topics and life situation.

It was further found from the results that the students taught ratio and proportion using the 'Mathematics as a Language of Science' method performed significantly better in the Volumetry Analysis than those taught the ratio and proportion using the Conventional Method. This finding further confirmed the superiority of the Mathematics as a Language of Science method over the Conventional Method.

These findings agree with that of Hamdal et al (2025) who found that secondary school students with strong prerequisite knowledge exhibited significantly higher mathematical literacy It also agreed with that of Maduka and Alex (2024) who found that improved mathematics background significantly enhanced the ability of the subjects to understand and teach science related topics. The findings were particularly in tandem with that of Deeken et al (2023) which was carried out in the University settings and found that basic mathematics content such as algebra and functions were consistently required for science related topics, and that students who were deficient in prerequisite mathematical skills had difficulties in understanding related science courses. The examination of the effect of two different methods (the Conventional Method and the Mathematics as a

Language of Science method) of teaching the prerequisite topic, ratio and proportion is a unique feature of this study.

V. Conclusion

From the results and findings from this study the conclusion could be drawn that prior knowledge of the topic ratio and proportion do enhance students' computational skill in volumetric analysis. The conclusion can also be drawn that the Mathematics as a Language of Science method which teaches the mathematics prerequisite topic ratio and proportion in relation to the science topic, volumetric analysis is the best for teaching mathematics topics to ensure knowledge transfer to related science topics.

VI. Recommendations

Based on the results and findings of the study, it was recommended that:

1. relevant mathematics prerequisite topics be taught and students understanding ensured before the related science topics are taught.
2. Mathematics and science teachers should collaborate in order to ensure effective teaching of science topics and related prerequisite mathematics topics.
3. Mathematics as a Language of Science approach which prove more effective than the Conventional Method should be used for the teaching of ratio and proportion and similar mathematics prerequisite topics.

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