Effects of Problem-Solving Models on Students' Achievement in Quantitative Chemistry Problems in Senior Secondary Schools in Uyo, Nigeria

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Abstract
The study investigated the relative effects of Ashmore, Casey and Frazer; Selvaratnam-Frazer; and Search, Solve, Create, Share, Problem Solving Models on students' achievement in quantitative chemistry problems in Uyo Local Government Area of Akwa Ibom State. Two research questions and two hypotheses guided the study. The study adopted a quasi-experimental research design in a non-randomized pretest, postest setting. The study sample comprised of 201 SS2 chemistry students, in public coeducational secondary schools in the study area, selected using multi-stage sampling technique. A researchers-developed instrument tagged "Achievement Test on Quantitative Chemistry Problems" (ATQCP) designed to measure students' achievement, with a reliability index of 0.84, was used in gathering data for the study. The data obtained were analysed using mean, standard deviation and analysis of covariance (ANCOVA). The result showed that students taught using Selvaratnam-Frazer Problem-Solving Model had the best achievement. Those taught using Ashmore, Casey and Frazer and Search, Solve, Create, Share model had comparable achievement. The result also indicated that gender had no significant influence on students' achievement. Consequently, it was recommended that chemistry teachers should use Selvaratnam-Frazer Problem-Solving Model in teaching quantitative chemistry problem-solving.

Keywords: problem-solving, academic, achievement, quantitative, chemistry

Introduction

One of the major goals in science education is the development of problem-solving skills which are critical in a highly technical, scientific, as well as complex modern society (Gongden, 2016). Problem-solving is the process of finding solutions to problem of any level of difficulty and complexity. As noted by Ehikhamenor (2013), problem-solving refers to the use of conceptual and procedural knowledge to derive solutions to problems. According to Seyhan (2015), problem-solving skills include the ability to reason analytically, think critically and create productively. It involves a series of abilities such as visualization, association, abstraction, comprehension, manipulation, reasoning, analysis, generalization, each needing to be managed and coordinated. The classroom learning experiences therefore need to be designed to scaffold and develop students' problem-solving skills.

Chi and Vanlehn (2010) observed that when students are trained to identify and understand the concepts behind the problems, the gap between good problem solvers and weak problem solvers diminishes. The students turn from being passive listeners or information receivers to active, free self-learners and problems solvers. It shifts the emphasis of educational programme from teaching to learning. To be actively engaged in solving sophisticated problems, students need to have a well-organized knowledge structure (Bledsoe & Flick, 2012) which in most instances is lacking among secondary school students. Consequently, they find quantitative chemistry problems difficult to undertake. This lack of well-organized knowledge structure requires the chemistry educators to intervene with different teaching and learning strategies to address students' problem–solving challenges and improve their capabilities in problem solving.

Chemistry is one of the science subjects that play an important role in national development. According to Fwatshak (2010), there is hardly any form of human endeavour going on in science without the application of chemistry. However, due to its abstract, complex, and conceptually demanding nature, chemistry has been found to be difficult for most secondary school students (Agogo & Onda, 2014). One of the goals of chemistry education is to develop students' problem-solving skills in the subject. Such skills are expected to help students overcome difficulties in some concepts of the chemistry curriculum. These are those mostly involved as quantitative problems such as electrolysis, mass and volume relationships, solubility and calculations involving chemical equations.

According to Okoh (2015), chemistry students find a number of concepts difficult to learn. These concepts mostly involve aspects of quantitative problems such as electrolysis, mass and volume relationships, solubility and calculations involving chemical equations. Within the last two decades, observation has shown that in spite of the various innovative teaching methods such as guided-discovery, co-operative learning, and animation instructional strategy introduced into science teaching in general and chemistry in particular, students'

ISSN: 2645-324X (Print)
ISSN: 2645-3223 (Online)

academic achievement in chemistry has consistently been below expectation and unimpressive (Shadreck & Chukunoye, 2018). This is buttressed by the poor performance of students in the West African Senior School Certificate Examinations (WAEC Chief Examiner Reports, 2018, 2019 and 2020). According to the West African Senior School Certificate Examination (WASSCE) Chief Examiners' reports (2020), low academic performance in chemistry has been attributed to factors such as difficulties in solving quantitative chemistry problems, students' poor communication skills, poor study habits, abstract nature of the subject, poorly equipped laboratory and lack of experienced chemistry teachers.

Quantitative problems constitute a major impediment in chemistry courses, both at the secondary and tertiary levels. They are multi-topic, complex and abstract in nature (Ibrahim, 2011). Agogo and Onda (2014) noted that they require students' deep problem-solving skills. According to Shadreck and Chukunoye (2018), to be able to solve quantitative problems in chemistry, students should not only possess good mastery of quantitative chemistry concepts, but they should also possess the ability to construct and balance chemical equations and use them in calculations of quantity of chemical substances.

The problem of poor academic achievement in chemistry among senior secondary schools students has been of much concern to chemistry educators. Achimugu (2013) asserts that for learning to be meaningful and effective in chemistry classrooms, the teacher should be able to select appropriate teaching strategy that will stimulate the interest of the learners and get them actively engaged in the process of learning. Teaching methods are the tools of the teacher in reaching the set goals and instructional objectives. If the tools are faulty or inappropriate, instructional goals and objectives may not be achieved.

Efforts to develop instructional strategies to enhance students' problem-solving abilities in science education have led to the development of many problem solving models such as: the Greeno Problem-Solving Model (GPSM) developed by Greeno (1978), Ashmore, Casey and Frazer Model developed by Ashmore et al. (1979), the Selvaratnam – Frazer Problem –Solving Model (SPSM) developed by Selvaratnam and Frazer (1982) and the Search, Solve, Create, Share (SSCS) Problem-Solving Model developed by Pizzini et al. (1988). The problem-solving models that are of major concern to this study are: Ashmore, Casey and Frazer Problem-Solving Model, Selvaratnam-Frazer Problem-Solving Model, and Search, Solve, Create, Share (SSCS) Problem-Solving Model. These problem-solving models are designed to help students to solve problems by proceeding in a logical sequence from a problem state to a solution state. The investigators are of the opinion that if these problem-solving models are used to teach quantitative chemistry problems, the students are likely to be better improved in terms of conceptual thinking, intuitive knowledge and insightful learning. Such students are also likely to display an improved level of achievement.

The Ashmore, Casey and Frazer Problem–Solving Model developed by Ashmore et al. (1979) is a four-step problem solving model. Specifically, details in Ashmore, Casey and Frazer Problem – Solving Model include: defining the problem goal; selecting information from the problem statement; selecting information from the memory and evaluation; solving the problem

On the other hand, the Selvaratnam - Frazer Problem-Solving Model devised by Selvaratnam and Frazer in 1982 has five steps which are: clarifying and defining the problem; selecting the key equation; deriving the relationship for the solution of the problem; collecting data, checking the units and calculating or solving the problem; and reviewing, checking through steps 1 – 4, confirming the units and learning from the solution.

The Search, Solve, Create, Share (SSCS) Problem-Solving Model developed by Pizzini et al. (1988) is a four-step cylindrical model which involves Searching, Solving, Creating and Sharing. The search phase is aimed at identifying the problem; the solve phase is aimed at solving the problem; the create phase is aimed at creating a product conclusion; and the share phase is aimed at promoting the settlement of the problem. This model allows for re-entry into the various stages of the model during the problem-solving process.

Chemistry teachers in classrooms do not use these models in solving quantitative problems in chemistry, instead they adopt a working forward strategy which is teacher-centred. Hence, the need for a paradigm shift from teacher-centred learning to student-centred learning through the use of appropriate problem-solving models. The study therefore examines the relative effectiveness of Ashmore, Casey and Frazer Problem-Solving Model, Selvaratnam-Frazer Problem-Solving Model, and Search, Solve, Create, Share (SSCS) Problem-Solving Model with a view to finding out the one that is more facilitative in solving quantitative chemistry problems in senior secondary schools in Nigeria. The traditional approach does not teach the basic procedural knowledge/strategies of solving quantitative problems. The implication is that students do not acquire the problem-solving procedures and skills required for successful performance. The question then is, how

ISSN: 2645-324X (Print)
ISSN: 2645-3223 (Online)

effective are Ashmore, Casey and Frazer Problem-Solving Model, Selvaratnam-Frazer Problem Solving Model, and Search, Solve Create, Share (SSCS) Problem-Solving Model in enhancing students' achievement in solving quantitative chemistry problems? This study therefore, seeks for answers to this question.

Research questions

To guide the study, the following research questions were raised for answering:

1. What are the students' achievement mean scores in quantitative chemistry problems when taught using the Ashmore, Casey and Frazer Problem Solving Model, Selvaratnam-Frazer Problem Solving Model, and Search, Solve, Create, Share (SSCS) Problem-Solving Model?
2. How do male and female students taught quantitative chemistry problems using the Ashmore, Casey and Frazer Problem Solving Model, Selvaratnam-Frazer Problem Solving Model, and Search, Solve, Create, Share (SSCS) Problem-Solving Model differ in their achievements?

Hypotheses

The following null hypotheses were formulated for testing at 0.05 alpha level:

Ho1: There is no significant difference in the achievement mean scores of students in quantitative chemistry problems when taught using the Ashmore, Casey and Frazer Problem-Solving Model, Selvaratnam-Frazer Problem-Solving Model and Search, Solve, Create, Share (SSCS) Problem-Solving Model.

Ho2: There is no significant difference between the achievement of male and female students in quantitative chemistry problems when taught using the Ashmore, Casey and Frazer Problem-Solving Model, Selvaratnam-Frazer Problem Solving Model, and Search, Solve, Create, Share (SSCS) Problem-Solving Model.

Methodology

The study adopted the quasi-experimental design in a non-randomized pre-test, post-test setting, using intact classes. The population of the study consisted of all the 4,559 SS2 Chemistry students in all the 14 public co-educational secondary schools in Uyo Local Government Area of Akwa Ibom state in 2019/2020 school year. The sample consisted of 201 Senior Secondary II students from six intact classes in six secondary schools in the study area, selected using multi-stage sampling technique. Firstly, the study area was stratified into urban and rural strata. Five schools were identified as rural schools while nine schools were identified as urban schools. Secondly, three urban schools and three rural schools were selected using simple random sampling technique. Finally, one arm of intact senior secondary II class from each of the selected urban and rural schools was randomly assigned to Experimental group I, Experimental group II and Experimental group III. Thus, one intact class each from the urban and rural schools were randomly assigned to Ashmore, Casey and Frazer Problem-Solving Model Group, Selvaratnam-Frazer Problem Solving Model Group, and Search, Solve, Create, Share (SSCS) Problem-Solving Model Group.

All the 201 students were pre-tested with "Achievement Test on Quantitative Chemistry Problems" (ATQCP). This instrument, with 25 items on quantitative problems in mass-volume relationship, was developed by the researchers for pre and post-tests. The items were developed on multiple choice options, A-D, with only one correct option. The instrument was face and content validated by three independent assessors: two content experts in chemistry education and one measurement and evaluation expert, all in the Faculty of Education, University of Uyo. The reliability index of the instrument was established using test-retest method. The data were analysed using Pearson Product Moment Correlation (PPMC). The analysis yielded a reliability coefficient of 0.84.

Teachers in the Experimental groups I, II, and III were trained on the procedures in teaching quantitative chemistry problem-solving using validated lesson notes developed by the researchers as related to the respective Problem-Solving Models adopted. The students in Experimental group I were taught using the Ashmore, Casey and Frazer Problem Solving Model, those in Experimental group II were taught using Selvaratnam-Frazer Problem-Solving Model, while those in Experimental group III were taught using Search, Solve, Create, Share (SSCS) Problem-Solving Model. At the end of the treatment, which lasted for two weeks, the ATQCP was administered to the students in all the groups as post-test. The data obtained were analysed using mean and standard deviation in answering the research questions, while analysis of covariance (ANCOVA) was used in testing the null hypotheses.

Presentation of results

The result of the analysis is presented below in line with the research questions and hypothesis.

Research question 1: What are the students' achievements mean scores in chemistry quantitative problems when taught using the Ashmore, Casey and Frazer Problem-Solving Model, Selvaratnam-Frazer Problem-Solving Model, and Search, Solve, Create, Share (SSCS) Problem-Solving Model?

ISSN: 2645-324X (Print)
ISSN: 2645-3223 (Online)

Table 1: Mean and standard deviation of students' pre-test and post-test scores classified by treatment groups

Treatment Groups	N	Pre-test		Post-test		Mean Gain Score
		$\bar{x}$	SD	$\bar{x}$	SD	
Ashmore, Casey & Frazer	67	4.16	2.34	22.39	8.16	18.23
Selvaratnam-Frazer	70	5.31	3.34	37.34	6.97	32.03
Search, Solve, Create, Share	64	5.58	3.24	20.41	5.72	14.83

Table 1 shows the pre-test and post-test mean scores and standard deviation scores of the three groups. The post-test pre-test mean scores of 37.34 and 5.31 respectively for those in Selvaratnam-Frazer group yielded the best mean gain score of 32.03. This is followed by the post-test pre-test mean gain score of 18.23 and 14.83 for those in Ashmore, Casey and Frazer, and Search, Solve, Create, Share groups respectively.

Ho1: There is no significant difference in the achievement mean scores of students in quantitative chemistry problems when taught using the Ashmore, Casey and Frazer Problem Solving Model, Selvaratnam-Frazer Problem-Solving Model, and Search, Solve, Create, Share (SSCS) Problem-Solving Model.

Table2: Summary of Analysis of Covariance (ANCOVA) of the students' post-test scores classified by treatment groups

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Decision at p<.05alpha
Corrected Model	11723.52	3	3907.84	78.72	.000	S
Pretest	27.89	1	27.89	.56	.454	Ns
Treatment	11607.28	2	5803.64	116.91	.000	S
Error	9779.24	197	49.64	-	-	-
Total	167654.00	201	-	-	-	-
Corrected Total	21502.76	200	-	-	-	-

R Squared = .545; Adjusted R Squared = .533

In table 2, the calculated F-ratio for the effect of instructional strategies at df 2, 197 is 116.91, while its level of significance is less than 0.05 in which the decision is based, indicating that there was a significant difference in the academic achievement in the concepts taught using the Ashmore, Casey and Frazer Problem-Solving Model, Selvaratnam-Frazer Problem Solving Model, and Search, Solve, Create, Share Problem-Solving Model. With this observation, the null hypothesis I was rejected. The direction of significance was determined using Scheffe Post Hoc test as reported in table 3.

Table 3: Scheffe Post Hoc homogeneous subset for post-test classified by treatment groups

Treatment Groups	N	Subset	
		1	2
Search, Solve, Create, Share	64	20.41	-
Ashmore, Casey & Frazer	67	22.39	-
Selvaratnam-Frazer	70	-	37.34
Sig.		.139	1.000

Mean scores for groups in homogeneous subsets are displayed.

The group mean scores in the homogeneous subset in table 3 show that students taught using Selvaratnam-Frazer Problem Solving Model significantly achieved better than those taught using the Ashmore, Casey and Frazer, and Search, Solve, Create, Share Problem-Solving Models in decreasing order. The difference in the achievement mean scores of students taught using Ashmore, Casey and Frazer, and Search, Solve, Create, Share Problem-Solving Models are statistically not significant.

Research question 2: How do male and female students taught quantitative chemistry problem using the Ashmore, Casey and Frazer Problem Solving Model, Selvaratnam-Frazer Problem Solving Model, and Search, Solve, Create, Share Problem-Solving Model differ in their achievements?

Table 4: Mean and standard deviation of students' pre-test and post-test scores classified by treatment groups and gender

Treatment Groups	Gender	N	Pre-test		Post-test		Mean Gain Score
			$\bar{x}$	SD	$\bar{x}$	SD	
Ashmore, Casey & Frazer	Male	35	4.63	2.60	21.34	7.11	16.71
	Female	32	3.66	1.92	23.53	9.15	18.77
Selvaratnam-Frazer	Male	34	4.76	2.87	37.85	6.92	33.09
	Female	36	5.83	3.67	36.86	7.08	31.03
Search, Solve, Create, Share	Male	36	5.97	3.35	21.14	5.31	16.38
	Female	28	5.07	3.06	19.46	6.16	13.63

Table 4 shows the pre-test and post test scores and standard deviation scores of male and female students in the experimental groups. A comparison of the results showed that female students taught using the Ashmore, Casey and Frazer Problem Solving Model had a higher mean gain score (18.77) than their male counterparts (16.71); the male students taught using the Selvaratnam-Frazer Problem Solving Model had a higher mean gain score (33.09) than their female counterparts (31.03); and the male students taught using Search, Solve, Create, Share Problem-Solving Model had a higher mean gain score (16.38) than their female counterparts (13.63).

Ho2: There is no significant difference between the achievement of male and female students in quantitative chemistry problems when taught using the Ashmore, Casey and Frazer Problem Solving Model, Selvaratnam-Frazer Problem-Solving Model and Search, Solve, Create, Share Problem-Solving Model.

Table 5: Summary of Analysis of Covariance (ANCOVA) of male and female students' post-test scores classified by treatment groups and gender with pre-test scores as covariate

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Decision at p<.05 alpha
Pre-test	36.99	1	36.99	.75	.389	s
Treatment	11613.93	2	5806.96	117.00	.000	s
Gender	.72	1	.72	.02	.904	ns
Treatment * Gender	149.89	2	74.94	1.51	.224	ns
Error	9628.71	194	49.63	-	-	-
Total	167654.00	201	-	-	-	-
Corrected Total	21502.76	200	-	-	-	-

R Squared = .552; Adjusted R Squared = .538

In table 5, the calculated F-ratio for the main effect of instructional strategies at df 2, 194 is 117.00 while its corresponding calculated level of significance is .000 alpha. This level of significance is less than .05 in which the decision is based indicating that there was a significant difference between the academic achievement of students in the concepts taught given the instructional models used. However, the F-cal value for the main effect of gender at df 1, 194 was .02 while its significant level is .904. This significant level is greater than .05 alpha in which the decision is based, indicating that the influence of gender on the students' achievement was not statistically significant; with this observation, null hypotheses II was upheld.

Discussion of the findings

The findings with regard to the effect of Ashmore, Casey and Frazer, Selvaratnam-Frazer and Search, Solve, Create, Share Problem-Solving Models on quantitative chemistry problem solving showed that there was a significant difference in the academic achievement of students. Students taught using Selvaratnam-Frazer Problem Solving Model achieved significantly better than those taught using the Ashmore, Casey and Frazer, and Search, Solve, Create, Share Problem-Solving Model groups. The better enhancing effect of Selvaratnam-Frazer Problem-solving model on students' achievement, which is in line with the findings of Fwatshak (2010) and Ibrahim (2011), could be attributed to the fact that Selvaratnam-Frazer Problem-solving model in addition to using sequential logical steps in problem-solving also encourages students to review their work after solving the problem. However, the finding is at variance with the findings of Shadreck and Chukunoye (2018) who observed that students taught using Ashmore, Casey and Frazer Problem-Solving Model performed significantly better than those taught using Selvaratnam-Frazer Problem-Solving Model.

On the influence of gender on student' achievements, it was observed that its influence was not statistically significant given the problem-solving models used. The reason could probably be due to the equal treatment given to both male and female in the treatment groups. This implies that when appropriate problem-solving models are used to teach quantitative chemistry problem solving, both male and female students will perform competitively in the same way. The finding is in agreement with the findings of Okoh (2015) and Shadreck and Chukunoye (2018) who observed that there was no significant influence of gender on students' performance in quantitative chemistry problem solving.

Conclusion

Based on the findings of the study, it was concluded that of the three problem-solving models investigated, Selvaratnam-Frazer Problem Solving Model is the most effective in facilitating students' achievement in quantitative chemistry problem-solving. Also, gender has no statistically significant influence on students' achievement in quantitative chemistry problem-solving.

Recommendations

The following recommendations were made based on the findings of the study:

1. Chemistry teachers should use Selvaratnam-Frazer Problem-Solving Model in teaching quantitative chemistry problem-solving.

2. Curriculum planners should ensure the incorporation of Selvaratnam-Frazer Problem-Solving Model in the teaching and learning of science concepts involving quantitative problems.

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