

Effect of Enhanced Process-Oriented Guided Inquiry Learning Strategy on Secondary School Chemistry Students' Integrated Science Process Skills Acquisition

¹Osuji, Patience Nkem, ²Owoyemi, Toyin E. & ³Adeyemo, Sunday A.

^{1,2&3}Department of Science and Technology Education
Faculty of Education, University of Lagos

Article DOI: 10.48028/ijprds/ijrfest.v4.i2.05

Abstract

Awareness has been created on learning science using inquiry strategies. Its implementation in secondary school chemistry classrooms in Nigeria has not been encouraging. Thus, this study was carried out to engage senior secondary school students in inquiry using Enhanced Process Oriented Guided-Inquiry Learning (EPOGIL) and to determine its effects on their integrated science process skills acquisition in some chemistry concepts. The influence of mathematical ability was also investigated. Teacher Demonstration (TD) was used as a control strategy. The study adopted a quasi-experimental pre-test, post-test non-equivalent control design. 6 intact classes used in the study were randomly assigned to treatment and control groups. Data was collected using the Test of Integrated Science Process Skills Acquisition (TISPSA) and Mathematical Ability Test (MAT). Data obtained were analysed using ANCOVA at 0.05 level of significance. The result of the study showed significant main effect of treatment on integrated science process skills acquisition. Based on the findings from the study, it is therefore recommended among others, that chemistry teachers should adopt strategies like EPOGIL to enhance their acquisition of integrated science process skills which will position them for success in higher studies and relevance in the 21st century world of work.

Keywords: *Enhanced Process-Oriented Guided Inquiry Learning; Integrated science process skills; Mathematical ability; Teacher Demonstration*

Corresponding Author: **Osuji, Patience Nkem**

Background to the Study

One of the objectives of teaching Chemistry in secondary schools is to enable students acquire basic theoretical and practical knowledge and skills in Chemistry as well as in Science, Technology and Mathematics (STM). Based on the above statement, it implies for any teaching and learning experience in a Chemistry classroom to be considered meaningful, the student should develop an understanding of the subject matter and acquire science process skills.

Science Process Skills (SPS) are tools used to investigate the world around us to construct scientific concepts (Eluket, Waswal & Lutta, 2019). Jack (2018), refers to SPS as activities that students carry out in scientific investigations to enable acquisition of knowledge and skills, while Temiz (2007), referred to SPS as important abilities required for an individual to be considered scientifically literate.

SPS are classified as basic or integrated. The basic SPS include skills like observing, inferring, measuring communicating, and predicting while the integrated SPS are controlling variables, defining operationally, formulating hypotheses, interpreting data, experimenting with, and formulating models. Science process skills are not only foundations for scientific inquiry, but also for the intellectual skills needed to learn scientific concepts and broad principles used in making valid, inductive references. According to Eya (2008), SPS are important to national development, they promote decision-making on scientific issues involving personal and civil issues; lead to increased productivity in mining and refining industries; and improve housing, transport and communication.

Acquisition of SPS is important during the learning process because SPS aid the students in learning and developing understanding (Ogunleye, 2013; Omiko, 2015; Irwanto, Rohaeti, Widjajanti and Suyanta, 2017; Fugarasti, Ramil and Muzzazinah, 2019). It also increases meaningful exploration of the environment which promotes problem solving in everyday situations. Yakar (2014), stated that to learn and understand science, students need to possess SPS. This view was buttressed by other studies which showed positive correlation between SPS and other learning outcomes including formal reasoning ability (Oloyede, 2012; Ozgelen, 2012), academic achievement (Delen and Kesercioglu, 2012; Osman and Vebrianto, 2013), scientific literacy (Kaya, Bahaci and Altuk, 2012) and scientific attitude (Zeidan and Jayosi, 2018).

Nigerian secondary school chemistry students' performance in external examinations has been a cause of concern to science educators. Evidence obtained from the West African Senior School Certificate Examinations (WASSC 2009-2019) statistics showed fluctuations in their performance despite the increase in the number of students who enrol for the examination. According to the WAEC CER (2018; 2019) reports, the students possess a low level of science process skills, an assertion which had been earlier reported by research studies (Omiko, 2015; Irwanto et al. 2017; Yamtinah, Masykuri, Ashadi and Shidiq, 2017). Between the year 2014 and 2019, students mean performance in the practical examinations was between 48 and 54%. This showed that even in the years where the overall performance increased, their

performance in practical examinations did not increase. Some reasons given for the trend in the practical examinations include students' lack of knowledge of laboratory procedures and inability to record observations and draw logical conclusions from observations made during tests (WAEC CER, 2017; 2019; Omoniyi and Torru, 2019). The situation calls for concerted efforts to be made on improving the students' science process skills.

Jack (2018), opined that student acquire scientific knowledge when they go through the process of thinking, analysing and interpreting facts. According to the paper, strategies that enable students utilise their intellect and apply their ability in thinking and reasoning more dynamically are important as they foster inquiry and manipulative skill, thereby discouraging rote learning. Eluket and others (2019), investigated the effect of experimental approach to teaching on students' SPS, the study which used an observation checklist, reported a positive effect of the treatment on students' SPS. Ibrahim (2016), investigated the effects of multimedia instructional strategies on students' SPS and reported positive effects of treatments.

However, Ayodele, Olatubosun and Daramola (2014), reported that students' acquisition of SPS is hampered by several factors including teacher factors, inadequate resources, large and overly crowded classes, and lack of time allocation on the timetable. The effect of teacher factors was buttressed by Karamustafaoglu (2011) and Ahmed and Siddiquee (2014) which reported that student teachers had problems with the acquisition of integrated SPS. If teachers have problems with these skills, it becomes difficult for them to impart these skills on their students, hence it is important that chemistry teachers are trained to have the knowledge and acquire the skills necessary for engaging students in activities that promote the development of SPS.

In the Nigerian science education system, efforts at promoting inquiry and meeting the needs of the 21st Century made the Government to state as one of the requirements of the National Policy on Education, that instructions in science should be concept-centred, activity-based and work-related (National Policy on Education, NPE, 2015). Despite these efforts, the teachers do not use inquiry methods to teach, they prefer the traditional lecture method (Ajaja, 2009; Ajeyalemi, 2011). Attempts at using inquiry are limited to the use of teacher demonstration in the laboratories. Teachers use demonstrations to illustrate a given concept, principle or skill the students is to verify for meaningful understanding (Adeoye, 2016).

Teacher demonstration is a teacher-centred method of teaching in which students' participation is limited to observing and asking questions. The method of teaching does not foster inquiry and manipulative skills, it promotes rote learning. Various reasons have been provided for inadequate use of inquiry including overloaded curriculum, inadequate time allotted for chemistry classes and practicals, inadequate chemistry laboratories consumables and non-consumables as well as reasons adduced that inquiry activities are time consuming for teachers who need to cover the syllabus when preparing for external examinations (Ajaja, 2009; Omoniyi and Torru, 2019).

Process-Oriented Guided Inquiry Learning (POGIL) is a strategy developed to enable students carry out inquiry in science classrooms. It works on the principles of cooperative and

collaborative learning. In using the POGIL strategy, groups of three or four students assigned specific roles including reader, recorder, analyst and presenter carry out inquiry making use of worksheets. The worksheets contain specially designed learning materials based on a learning cycle of Exploration, Concept Invention and Application. They contain models in the form of graphs, equations, or tables that are used to lead the students to explore the concept. Questions are used to guide the students to develop a general idea of the concept and apply the general ideas to specific problems that they encounter in the traditional classroom (DeMatteo, 2016). Studies on the use of POGIL have reported that the strategy led to enhanced students' outcomes including improvement in aspects of practical chemistry (Omoniyi and Torru, 2019).

Enhanced POGIL (EPOGIL) is a strategy designed by the researcher to assist the secondary school chemistry teachers and students who are used to teacher centred classrooms teacher-centred classroom transit to using student-centred one. It involves the use of POGIL materials in the 7E learning cycle paradigm. The steps in this cycle include: *Elicit, Engage, Explore, Explain, Elaborate, Evaluate and Extend* (Eisenkraft, 2003). While retaining the main qualities of a POGIL workshop, the EPOGIL strategy includes elements that enable the teacher to explore students' prior knowledge as well as opportunities that arouse curiosity as well as challenge the students' process skills. Studies have reported positive effects of the use of POGIL and 7E learning strategy on students' achievement, self-regulated learning skills, critical thinking skills and their scientific reasoning (Adesoji and Idika 2015; De Gale and Boisselle, 2015; Balta and Sarac, 2016; Zyraggen, 2018; Omoniyi and Torru, 2019; Aiman, Hasyda and Uslan, 2020). However, these strategies have received relatively inadequate research attention in the Nigerian educational system.

Research-based evidence (Adigwe, 2012; Awofala, 2017) established that a relationship exists between mathematics and chemistry. According to Potgeiter, Harding and Engelbrecht (2008), mathematics is important in Chemistry. This opinion was buttressed by Adkins and Noyes (2018) which stated that success in disciplines like chemistry is built on the level of mathematics, and that the mathematical ability of students is an important predictor of success in Chemistry.

Mathematical tools of representations like tables, graphs and equations that are useful for communicating and reasoning are very important in Chemistry. Most of the topics in the Nigerian Secondary School Chemistry curriculum require basic knowledge of mathematics. However, the Chemistry students usually find these topics with strong mathematical base difficult to understand. WAEC CER (2017) stated that Nigerian chemistry students perform poorly in aspects that require mathematical computations in the Senior School Certificate Examinations. They face problems in chemistry because of insufficient mathematics preparation and because students do not apply what they learn in mathematics classes to other situations.

Studies have shown a significant positive relationship between students' mathematical achievement and their performance in chemistry (Adigwe, 2012; Adeoye and Ajeyalemi, 2018). However, there is a dearth in literature of the effect of students' mathematical ability on their acquisition of integrated science process skills.

Based on the foregoing reports, the current study determined the effect of enhanced POGIL strategy on students' acquisition of three integrated science process skills (formulating hypotheses, controlling variables and interpreting data) in redox, stoichiometry, rate of chemical reaction and chemical equilibrium. The influence of mathematical ability on students' acquisition of these skills was also investigated. Three hypotheses were formulated to guide the study.

- H₀₁:** There is no significant effect of treatment on secondary school chemistry students' acquisition of integrated science process skills in chemistry.
- H₀₂:** There is no significant influence of mathematical ability on secondary school students' acquisition of integrated science process skills in chemistry.
- H₀₃:** There is no significant interaction effect of treatment and mathematical ability on secondary school students' acquisition of integrated science process skills in chemistry.

Materials and Method

The study adopted a Pre-test Post-test Control Group Quasi-Experimental Research design schematically represented as:

E _(EPOGIL)	0 ₁	X ₁	0 ₂
Control	0 ₃	X ₂	0 ₄

The population for the study consisted of the three thousand eight hundred and fifty-three (3,853) senior secondary (SS2) Chemistry students in Education District II of Lagos State. A total of three hundred and fourteen (314) SS2 students from six intact classes were randomly assigned treatment and control groups for the study.

A total of four instruments were used for the study comprising:

1. Enhanced POGIL Instructional Guide (EPOGILIG)
2. TD Instructional Guide (TDIG)
3. Mathematical Ability Test (MAT)
4. Test of Integrated Science Process Skills Acquisition (TISPSA)

MAT consists of twenty (20) multiple choice items with four (4) options labelled A to D. MAT was constructed by the researcher in order to evaluate the mathematical ability of the students in relation to chemistry. This test was used to classify the sampled students into three levels of mathematical ability: high, moderate and low. The items for the MAT were adapted from Dundar and others (2016). Each of the test items carries a score of 1 mark giving a total of twenty (20) marks. Students' scores were converted into percentages which was used to group them viz: 70 – 100 (high); 40 – 69% (moderate); and 0 – 39%. A reliability coefficient of 0.73 was obtained for the mathematical ability test using Kuder-Richardson formula 20 (KR-20).

TISPSA consisted of 20 multiple choice items with four options A, B, C, and D and used to measure students' acquisition of integrated science process skills in chemistry. The test questions were constructed by the researcher making use of the integrated science

process skills set identified by Burns, Okey and Wise (Temiz, Tasar and Tan, 2006). The items were designed to measure the identified skills based on chemistry content and principles in topics which the students are expected to be familiar with and not necessarily on the concepts used for the study. Each question is followed by four options, one of the options is correct while the other three options are distractors. Each question has a score of 1 mark giving a total of twenty marks. Students can either get a score of 1 or 0 depending on the options they choose. The test duration is forty (40) minutes. The test of integrated science process skills acquisition items gave a reliability coefficient of 0.71.

The permission of the principals was obtained for the use of the teachers and the SS 2 chemistry students. The chemistry teachers were given training sessions on the use of the instructional strategy. The researcher also provided some of the materials needed for the study. The MAT was administered to the students at the beginning of the study to group the students into different mathematical ability levels (high, moderate and low).

The TISPSA was administered as pre and post tests to both the experimental and control groups at the beginning and end of the treatment period which lasted for seven weeks. The data collected was analysed using descriptive statistical tools including mean, standard deviation, percentages and inferential statistics. The hypotheses were tested using Analysis of Covariance (ANCOVA), Scheffe post hoc test was used where significant mean effects were observed. The hypotheses were tested at 0.05 level of significance.

Results and Discussion

Research Hypothesis Ho1: There is no significant effect of treatment on chemistry students' acquisition of integrated science process skills.

The Ancova table (Table 1) shows that there is significant main effect of treatments on students' integrated process skills acquisition ($F_{(1,314)} = 50.002$; $\eta^2=0.195$) at 0.05 level of significance. This implies that there is significant difference in the post-test scores of students' integrated process skills acquisition between the experimental and control groups with an effect size of 19.5%. The percentage contribution of the independent variable to the variance of the dependent variable is 70.3%. Thus, the null hypothesis Ho1 was rejected. The Estimated Marginal Means of students' post-test scores on integrated science process skills acquisition of each group (Table 2) indicates that the students in the experimental group (EPOGIL) obtained the higher estimated marginal means in integrated science process skill acquisition ($x= 14.26$) than those of the control (TD) group ($x= 11.69$). This confirms that EPOGIL is a better strategy in promoting students' acquisition of integrated science process skills.

H₀2: There is no significant influence of mathematical ability on the chemistry students' acquisition of integrated science process skills.

Table 1 (Ancova Analysis), shows that the $F_{(2,314)} = 81.368$; $\eta^2=0.282$) at 0.05 level of significance. This implies that there is significant significant influence of mathematical ability on the chemistry students' integrated science process skills acquisition with an effect size of 28.2%. Thus, the null hypothesis Ho2 was rejected.

The descriptive statistics of students' post-test scores based on their mathematical ability levels (Table 3) shows that students with high mathematical ability levels had the highest mean scores ($x = 13.08$), followed by students with moderate mathematical ability ($x = 12.66$) and those with low mathematical ability ($x = 11.42$). This confirms the effect of mathematical ability on students' acquisition of integrated science process skills.

H₀₃: There is no significant interaction effect of treatment (EPOGIL and TD) and mathematical ability on the chemistry students' acquisition of integrated science process skills.

Table 1 shows that $F_{(4,314)} = 120.231$; $\eta^2 = 0.107$ which is significant at 0.05 level of significance. This implies that there is significant interaction effect of treatment and mathematical ability on chemistry students' integrated science process skills acquisition with an effect size of 10.7%. Thus, null hypothesis H₀₃ was rejected.

The descriptive statistics of students' post-test scores based on the interaction effect of treatment and mathematical ability levels is shown on Table 4. From the table, students in the experimental group (EPOGIL) had higher post-test scores based on the mathematical ability levels. The students had mean scores of ($x = 17.93$) for high; ($x = 14.9$) for moderate; and ($x = 10.46$) for low mathematical ability levels. Students in the control group had mean post-test scores of ($x = 13.79$, 11.07 and 9.5) for high, moderate and low mathematical ability levels respectively. The result confirms the superiority of EPOGIL over the control strategy based on students' mathematical ability levels.

The TD strategy, though a means of promoting inquiry, does not allow students' interaction or manipulation. The absence of these elements could be linked to students' poor outcome in the acquisition of integrated science process skills. The experimental strategy provided opportunities for students to carry out inquiry through the guidance of the teacher. The students study the models given, analyse the information provided, carry out investigations (when applicable), write and present these reports. In the use of TD, students passively watch the teacher demonstrate and explain the concepts involved to them (Nworgu and Otum, 2013; Omoniyi and Torru (2019). The finding of this study is consistent with Eluket and others (2019) which reported positive influence of hands-on activities on science process skills acquisition. This finding is also consistent with studies which stated that teacher demonstrations may not serve the goals of laboratory work, especially in the area of skills acquisition (Treagust and Tsui 2014; Silitonga et al, 2021).

There was a positive influence of mathematical ability on students integrated science process skills acquisition. Certain mathematical sub-skills, like causal skills are related to integrated science process skills. Causal skill involves the development of hypotheses, statistical reasoning and interpretation of data and graphs. Students with high mathematical ability possess causal skills, and can reason to identify patterns and relationships; these abilities are related to the integrated science process skill of identifying variables. Students who possess causal skills can develop hypotheses, and state them in testable forms they can also prepare and interpret tables and graphs, these activities fall under the integrated process skill of data interpretation.

The result showed statistically significant interaction effect of treatment and mathematical ability on students' acquisition of integrated science process skills. Mathematical ability includes not only quantitative calculations, but also, qualitative aspects as well as inductive and deductive skills. Therefore, it is expected that when students with high to moderate mathematical abilities are exposed to strategies that require them to apply their reasoning skills, they are able to improve in their acquisition of skills. Since the experimental strategy involved the students in reasoning to find patterns and relationships, their mathematical abilities are improved thereby leading to increase in acquisition of integrated science process skills. It is therefore necessary for the students to be made aware of the importance of mathematics and encouraged to improve their mathematical skills.

Conclusion

The study established that Enhanced Process-Oriented Guided Inquiry Learning is an effective strategy for improving students' acquisition of integrated science process skills. Chemistry teachers are encouraged to use strategies that enable students take ownership of their learning by providing opportunities for students to interact with their peers and the learning materials in order to make meaning. Eliciting students' prior knowledge and engaging them before introducing the topics are useful ways of capturing and sustaining students' interest throughout the class period.

Table 1: ANCOVA Summary of Post-Test Scores on Integrated Science Process Skills Acquisition in Chemistry

Tests of Between-Subjects Effects						
Dependent Variable: Integrated Science Process Skills Acquisition						
Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2832.783 ^a	20	141.639	52.425	.000	.717
Intercept	4848.753	1	4848.753	1794.688	.000	.813
ISPSA Pretest	15.422	1	15.422	5.708	.071	.014
Treatments	270.186	1	135.093	50.002	.000	.195
Math Ab	439.668	2	219.834	81.368	.000	.282
Treatments × Math Ab	134.227	4	33.557	120.231	.000	.107
Error	1118.514	141	2.702			
Total	73846.000	143				
Corrected Total	3951.297	313				

a. R Squared = .717 (Adjusted R Squared = .703)

Table 2: Estimated Marginal Means Analysis of Students' Post-Test Scores

Dependent Variable: ISPSA Post-Test

TREATMENTS	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
EPOGIL	14.258 ^{a,b}	.251	13.764	14.752
TD	11.686 ^{a,b}	.192	11.309	12.063

a. Covariates appearing in the model are evaluated at the following values: TIPSPRE = 3.589.

b. Based on modified population marginal mean.

Table 3: Descriptive Statistics of Students' Post-Test Scores Based on Mathematical Ability Levels

Mathematical Ability	N	Mean	Std. Deviation	Std. Error
High	59	13.08	2.85	.30
Moderate	166	12.66	3.12	.17
Low	89	11.42	1.53	.31

Table 4: Interaction Effect of Treatment and Mathematical Ability on Integrated Science Process Skills Acquisition

Treatments	Mathematical Ability	N	Mean	Std. Deviation
EPOGIL	High	35	17.93	.92
	Moderate	77	14.90	2.28
	Low	23	10.46	2.26
TD	High	24	13.79	1.42
	Moderate	89	11.07	1.37
	Low	66	9.50	1.68

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