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Simulated Laboratory and Enriched Laboratory Guide Material Experiments as Catalysts for Improving Basic Science Students' Achievement

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Laboratory experiments promote conceptual understanding and enhance achievement in science. Inadequate exposure of students to basic science practical has weakened the foundation in science teaching and learning at the basic education level in Nigeria. Thus, students' achievement in basic science failed to significantly predict later achievement in Biology, Chemistry, and Physics. Therefore, the study determined how achievement in basic science of male and female students with different future career interests in science are affected by simulated laboratory (SL) and enriched laboratory guide material (ELGM) experiments which were developed. Bruner's constructivism provided the framework while the study utilised quasi experimental design having the pre-test-post-test control group with a 3 x 2 x 2 factorial matrix. The sample comprised 277 (130 males and 147 females; ± 17 years old) junior secondary three (JSIII) students randomly selected from six secondary schools of which equal number have functional Computer and Physics laboratories or without. Data were collected using Achievement test in basic science (r = 0.87) and future career interest in science (FCIS) (r = 0.99), while seven hypotheses were tested at 0.05 level of significance with the aid of analysis of covariance, estimated marginal means (EMM), and Scheffé post-hoc analysis. The findings of the study reveal that treatment and FCIS were significantly effective while gender had no significant effect on students' achievement in basic science. It is, therefore, recommended that SL and ELGM experiments be used to teach basic science practical taking cognizance of students' FCIS.

Keywords: simulated laboratory, enriched laboratory, basic science

Introduction

Laboratory experiment plays significant roles in concretizing teaching and learning of science subjects. It ensures activity-based interactive sessions which develop learners' interest and improve their achievement in the subjects. It facilitates the teaching and learning of skills, concepts, and attitudes and understanding the nature of science (Bates, 1988).

Laboratory experiments are usually conducted by using apparatus, equipment, and materials based on the provisions of a laboratory manual or guide. However, students at the basic education level in Nigeria are hardly

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exposed to laboratory experiments in basic science. They are taught using the conventional (lecture-demonstration) strategy (Akinsola, 1999a).

Students are rarely engaged in hands-on activities which could promote conceptual understanding and enhance achievement in science. Also, the Basic Education Certificate Examination (BECE) in basic science do not assess practical.

Consequently, students have poor knowledge of science practical which is an important part of science teaching and learning. In spite of impressive performance in BECE (2008-2015) in basic science as indicated in Table 1, many students did not earn distinctions (A1, B2, and B3) and credits (C4, C5, and C6) in Biology, Chemistry, and Physics in the West African Senior School Certificate Examinations (2010-2013) as shown in Figure 1. This contradicts the findings of Olatoye and Afuwape (2004) that students' achievement in integrated science (now basic science and technology) significantly predicts later achievement in Biology, Chemistry, and Physics in that order.

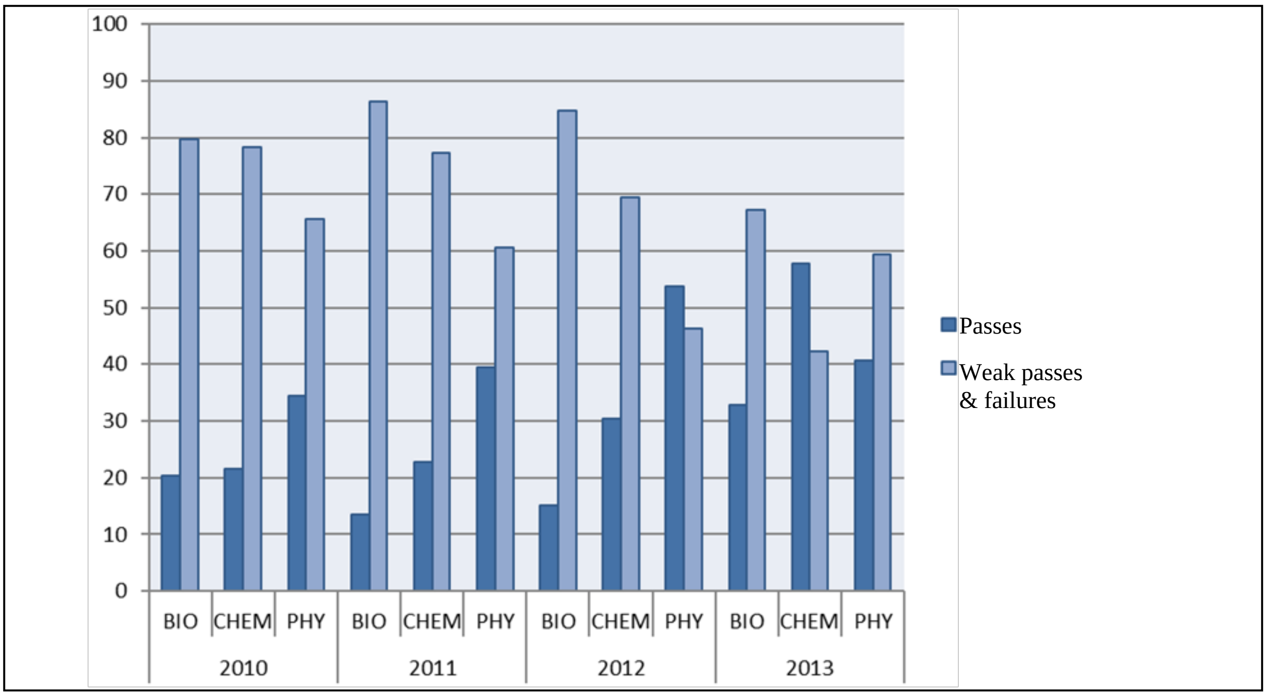

Figure 1. Percentage of Oyo State students' performance in WASSCE science subjects (May/June 2010-2013).

Table 1

Percentage Distribution of Oyo State Students' Performance in the BECE in Basic Science (2008-2015)

Year	Distinction + Credit	Pass	Failure	Total (100.0%)
2008	59,683 (74.5%)	14,138 (17.7%)	6,249 (07.8%)	80.070
2009	47,087 (55.4%)	29,935 (35.2%)	8,012 (09.4%)	85.034
2010	61,508 (76.5%)	18,081 (22.5%)	766 (01.0%)	80.355
2011	44,479 (59.0%)	15,640 (20.7%)	15,318 (20.3%)	75.437
2012	52,899 (59.4%)	25,466 (28.6%)	10,682 (12.0%)	89.047
2013	47132 (59.9%)	20,723 (26.3%)	10,878 (13.8%)	78.733
2014	69663 (78.2%)	17,988 (20.2%)	1,457 (01.64%)	89.108
2015	76,889 (79.74%)	19,501 (20.23%)	31 (00.03%)	96.421

Source: https://tafpublications.com/gip_content/paper/jahss-4.4.3pdf

One of the Factors Identified in Literature to be Responsible for Students' Abysmal

One of the factors identified in literature to be responsible for students' abysmal performance in science public examinations is inadequate exposure to science practical activities (Akinsola, 1999b; Omilani, 2015; Isa, 2007). Ajeyalemi (2011) reported that science laboratory and equipment needed to conduct experiments stated in the curriculum were absent in more than 90% of public schools in Nigeria. Also, there are no functional laboratory apparatus, equipment and materials in Biology, Chemistry, and Physics (Akinsola & Igwe, 1999; Taiwo, Adeniji, & Muazu, 2012).

Previous studies focused on strategies which could be used to improve students' achievement in Biology (Akubuilo, 2004), Chemistry (Ogbu, 2012; Makinde, 2005), Chemistry (Akinsola & Igwe, 2002), Physics (Onwioduokit & Akinbobola, 2005), and Integrated Science (Oyediran, Agoro, & Fabiyi, 2004).

However, scholars did not address challenges posed by the absence of laboratories and laboratory guide material to teach basic science practical (Akinsola & Igwe, 2001). In order to make up for this deficiency in previous strategies, Shaheen and Khattab (2005) recommended the use of simulated laboratory (SL) experiments where there are no laboratories and Ogunbowale (2012) advocated the adoption of enriched laboratory guide material (ELGM) experiments where there are functional laboratories to conducting basic science practical.

SL experiment is an application of computer assisted/aided learning (CAL) to conducting experiments in the laboratory (Akanbi, 2005; Ogunkunle, 2018). It consists of either still or mobile images/models of real apparatus, equipment, and materials. These models could be assembled by "drag and drop" using high level programming language, such as Action Script and JavaScript. It affords students the opportunity to observe, measure, input, and store values of the variables during the experimental procedure. It is available online or as stand-alone application package in compact disc (CD)-ROM and digital video disc (DVD) among others (Saka, 2005).

Stand-alone application packages are not affected by limited internet connectivity and other challenges associated with using online simulations. This is because "stand-alone applications are computer programmes that run without connection to telephone, television, satellite, or other electronic transmissions" (Olutunmbi, 2004). Thus, it was adopted, developed, and used in this study. Basic Science Simulated Laboratory Experiments Software Package (BSSLESP) was developed by using Adobe Complete Suite (CS6) which consists of Adobe Fireworks, Adobe Flash Professional, User Interface, Adobe Audition, and Adobe After Effect.

SL experiments have been shown to enhance students' achievement in science. Kim (2007) found that 3D virtual reality simulated experiment significantly improved 5th-grade pupils' achievement in science more than the traditional 2D visuals. Geban, Askar, and Özkan (2010) and Tüysüz (2010) observed more positive effects of computer-simulated experiments (CSE) on 9th-grade students' achievement in Chemistry than traditional teaching strategies. Huppert, Lomask, and Lazarowitz (2010) concluded that simulated experiment produced significantly higher academic achievement of 10th-grade students in Biology than the "hands-on" experiment. Kelly, Bradley, and Gratch (2008) reported a significant positive effect of SL experiments on students' achievement in undergraduate Physics courses more than the traditional laboratory experiments. Bartholomew, Oyedepo, and Yusuf (2011) found that SL experiments improved the achievement of higher national diploma students in Electronic Engineering more than the "hands-on" laboratory experiments.

ELGM experiment is the use of ELGM to conducting basic science experiments in schools where there are functional Biology, Chemistry, and Physics laboratories. The ELGM contains activities which will enable the students to explore and discover relationship(s) between experimental variables in a physical laboratory (Ogunkunle, 2018). It minimizes potential equipment damage, time wasted, injury, and material wasted while maximizing potentials for generating usable data (National Council of Educational Research and Training [NCERT], 2014; Pyatt & Sims, 2007). It could be produced as hard copies or delivered in electronic form (Hofstein & Lunetta, 2004). An ELGM was developed and validated to conducting experiments on reflection of light at a plane surface and relationship between potential difference and electric current in this study.

Literature revealed that the use of ELGM experiments could improve students' performance in science. Ertepinar and Geban (2006) observed that 8th-grade students exposed to investigative-oriented laboratory activities performed significantly better in science than those exposed to worksheet-oriented laboratory activities. Freedman (1998) found a significantly higher achievement of students in science for hands-on laboratory instruction than the conventional instructional strategy. Dechsri, Jones, and Heikkinen (1998) observed that a Chemistry laboratory manual enriched with pictures or diagrams enhanced university students' achievement in general Chemistry course than the Chemistry laboratory manual without pictures or diagrams enrichment. It is evident that most researchers conducted on the effectiveness of SL and ELGM experiments were not carried out in basic science. They were performed among the senior secondary school, higher national diploma, and university students. Hence, this study determined the effects of SL and ELGM experiments on students' achievements in basic science.

Gender is one of the two moderator variables which were investigated in this study. Research findings were divergent on the influence of gender on achievement of males and females in science. Farooq, Chaundhry, Shafiq, and Berhanu (2011) observed that girls performed significantly better than boys in English and Mathematics as well as in the overall achievement in the 9th-grade annual examination of secondary school students in Pakistan. Also, Mishra and Yadav (2013) reported that girls performed significantly better than boys in knowledge based of science when taught using activity based approach in India class VII high school.

On the other hand, Okafor (2007) reported that achievement in science for male were better than female students significantly. However, several studies have shown that there was no significant gender difference in secondary school students' achievement of males and females exposed to computer assisted instruction (CAI) (Oludipe, 2012; Murugan & Jseena, 2010; Yusuf & Afolabi, 2010). Thus, there is need to examine achievement of boys and girls in basic science.

The second moderator variable is future career interest in science (FCIS). It is an expression of preference for a profession in science or related field which one intends to practice after formal schooling. It is usually influenced by gender-role stereotyping, informal science experience, future jobs expectation, absence of career talk, and inadequate career information on science-related options among others (White & Harrison, 2012; Wyss, Heulskamp, & Siebert, 2012; Wang & Staver, 2010; Farenga & Joyce, 1999). FCIS has been found to significantly improve students' achievement in science (Adodo & Gbore, 2012; Park, Khan, & Petrina, 2009; Osokoya, 2003). However, Odetoyinbo (2004) found no significant contribution of FCIS to junior secondary three (JSIII) students' achievement in integrated science in Oyo State. Consequently, there is need to examine the how career interest affects the achievement of students in basic science.

Hypotheses

The under listed null hypotheses were tested at 0.05 level of significance.

$H_0$1: There is no significant main effect of treatment on students' achievement in basic science.

$H_0$2: There is no significant main effect of gender on students' achievement in basic science.

$H_0$3: There is no significant main effect of FCIS on students' achievement in basic science.

$H_0$4: There is no significant interaction effect of treatment and gender on students' achievement in basic science.

$H_0$5: There is no significant interaction effect of treatment and FCIS on students' achievement in basic science.

$H_0$6: There is no significant interaction effect of gender and FCIS on students' achievement in basic science.

$H_0$7: There is no significant interaction effect of treatment, gender and FCIS on students' achievement in basic science.

Theoretical Framework

The use of laboratory experiments to enhance science teaching and learning is rooted in Bruner's constructivist theory and discovery learning. According to Bruner (1966), learning occurs when a learner can construct new ideas or concepts (knowledge) using the knowledge existing in his/her cognitive structure. Cognitive structure means schema or mental models. A schema is the knowledge that a learner has acquired before (prior knowledge). Bruner (1966) believed that constructing new knowledge involves the ability of a learner to identify similarities or differences between new and existing knowledge and adjust his/her mental models or schema to accommodate the categorized new experiences or information. Constructivist teaching believes in the use of strategies that could guide a learner to discover principles, discuss, appreciate, and verbalize the new knowledge. Bruner (1961) therefore recommends discovery learning—"learning by doing". It occurs whenever a learner is not provided with exact answer but rather the materials in order to find out the answer on his/her own while drawing on his/her own experience and prior knowledge. Bruner's ideas of constructivist theory and guided discovery learning strategy find relevance in the present study, because learners are made to construct new knowledge from their personal and group past experiences which they acquired through their active participation in group conduct of SL and ELGM experiments in small groups/teams of five members.

Method

The study employed quasi-experimental design having the pre-test-post-test control group and 3 x 2 x 2 factorial matrix to determine how SL and ELGM experiments improved/enhanced achievement of junior secondary school students in basic science in Oyo State, Nigeria. Ibadan North, Ibadan South-East, and Ibadan South-West, as well as Afijio, Oyo-East, and Oyo-West were randomly selected from local government areas in Ibadan and Oyo. Schools with functional Computer and Physics laboratories as well as those without were purposively sampled for the study. One hundred and thirty male and 147 female students with an average age of 17 years from six randomly selected intact classes of JSIII intact classes were randomly assigned to SL (110), ELGM (60), and control/CEL (107) experiments. The junior secondary class three was used, because Light and Electrical Energy had been planned for teaching under the theme "You and Energy" in basic science in the class by the Nigerian Educational Research and Development Council (NERDC) since 2006 and reiterated in

2012. All selected schools had not taught light and electrical energy at the junior secondary level. Also, the two topics were perceived by Oyo State junior secondary teachers as being difficult to teach in a preliminary study. Hence, the purposive selection of these topics, experiments on reflection of light as well as relationship between potential difference and electric current for the study.

Two response and three stimulus instruments were used in this study. Achievement Test in Basic Science (ATBS) sought information on the amount of theoretical knowledge acquired by the students in relation to light and electrical energy of JSIII section of the NERDC (2012) curriculum for basic science for junior secondary. It consists of Sections A and B. Section A was used to collect students' personal data. Section B contains 40 (20 items from each of light and electrical energy) multiple choice items, each item having four options: a, b, c, and d constructed by the researcher. The questions are of parallel standard to those of the BECE. The researchers developed the instrument, because ATBS is based on theories of experiments conducted by the students whereas BECE contains topics in the NERDC basic science curriculum for junior secondary. Each correct option is allotted one mark. The instrument has a reliability index of 0.87 obtained by Kuder-Richardson formula 20 (KR-20). Its content validity, objectivity of its scoring key and clarity of its items was established by experts in science education and practicing basic science teachers.

FCIS questionnaire was used to collect information on the type of profession/course of study students hope to go into after schooling. It consists of Sections A and B. Section A contains students' personal data. Section B is a checklist of 38 (science-related = 28 and non-science related = 10) professions/courses of study, from which the learner indicated the preferred future career. The list was adapted from Osokoya (2003) Student Career Aspiration (SCA) and guided by the 2015/2016 e-Bronchure of the Joint Admissions and Matriculation Board (JAMB) (2015/2016). Professions/courses of study which require that a candidate should possess the senior secondary certificate examination credit pass in at least one of Biology, Chemistry, and Physics for admission into the university through JAMB were classified as science-related while those which do not require credit pass in any of such science subjects were grouped as non-science related. The instrument was given face-validity by experts in science education and it has a test-retest reliability index of 0.99 obtained by Cronbach's Alpha formula.

The stimulus instruments are instructional guide on simulated laboratory (IGSL), IGELGM, and conventional (expository) laboratory (IGCEL) experiments. Each guide contains the procedure for conducting the respective experiments. The steps fall into six stages: introduction, discussion of basic concepts relevant to each experiment, demonstration of the experiment by the facilitator (teacher), group performance of the experiment by the students, deduction, and verification of novel relationship(s) between experimental variables and report writing. However, students in the CEL group were not required to deduce and verify relationship(s) among experimental variables. Treatments lasted seven weeks. Analysis of covariance (ANCOVA) was deployed to analyse the data collected in order to test the hypotheses at 0.05 level of significance. The Estimated Marginal Means (EMM) was computed to determine the posttest mean scores for different groups. The direction of significance was ascertained using Scheffé post-hoc analysis.

Results

H01: There is no Significant Main Effect of Treatment on Students' Achievement in Basic Science

Table 2 reveals that there was significant main effect of treatment on students' achievement in basic science ($F_{(2,264)}$ = 25.88, p < 0.05; partial η^2 = 0.164). Thus, the treatment had significant main effect on students' posttest mean achievement score in basic science with an effect size of 16.4%. Therefore, Hypothesis 1 is rejected. EMM were calculated as post-test mean scores of the groups and these are displayed in Table 3.

Table 2

Summary of ANCOVA of Post-Test Achievement Scores in Basic Science by Treatment, FCIS, and Gender

Source	Type III sum of squares	*df*	Mean square	*F*	Sig.	Partial eta squared
Corrected model	2582.488[a]	12				
Intercept	60610.594	1	215.207	7.057		
Pre-achievement	279.592	1	60,610.594	1,987.608		
Main effect				9.169	0.000	0.243
Treatment	1578.072	2	279.592		0.000	0.883
Gender	0.300	1	789.036	25.875	0.003	0.034
FCIS	124.263	1	0.300	0.010	0.000*	0.164
2-Way Interaction				4.075	0.921	0.000
Treatment x gender	70.545	2	124.263		0.045*	0.015
Treatment x FCIS	63.858	2	35.272	1.157	0.316	0.009
Gender x FCIS	5.230	1	31.929	1.047	0.352	0.008
3-Way Interaction				0.171	0.679	0.001
Treatment x gender x FCIS	3.360	2	5.230		0.946	0.000
Residual (Error)	8,050.479	264	1.680	0.055		
Total	15,7304.000	277	30.494			
Corrected total	10,632.968	276				

Notes. [a]. R squared = 0.243 (Adjusted R squared = 0.208) *Significant at p < 0.05.

Table 3

EMM of Post-Test Achievement Scores in Basic Science by Treatment Groups

Group	*N*	*Mean*	Std. error	95% confidence interval	
				Lower bound	Upper bound
Treatment I (SL)	110	19.395[a]	0.551	18.311	20.479
Treatment II (ELGM)	60	24.907[a]	0.957	23.022	26.791
Treatment III (Control/CEL)	107	24.771[a]	0.614	23.562	25.981

Note. [a]. Covariates appearing in the model are evaluated at pre-achievement score = 3.4152.

Table 3 indicates that the ELGM experiment group obtained the highest post-test achievement mean score (24.91) in basic science followed by the control/CEL experiment group (24.77) and the SL experiment group (19.40) respectively. This implies that students exposed to the ELGM experiment in basic science performed better than those exposed to the control/CEL and SL. Furthermore, the sources of the significant effect of treatment on achievement in basic science were traced by using Scheffé post-hoc test as shown in Table 4.

Table 4

Scheffé Post-Hoc Analysis of Treatment on Students' Achievement in Basic Science

Group	*N*	*Mean*	SL	ELGM	Control/CEL
1. Treatment I (SL)	110	19.395		*	*
2. Treatment II (ELGM)	60	24.907	*		
3. Treatment III (Control/CEL)	107	24.771	*		

Note. *Pairs of groups significantly different at p < 0.05.

Scheffé post-hoc test on Table 4 reveals that the posttest achievement mean score (19.40) of students exposed to SL was significantly different from the mean score (24.91) of those exposed to ELGM. Also, the post-test achievement mean score (19.40) of students in the SL group was significantly less than the mean score (24.77) of the CEL. Thus, the significant differences of the treatment on students' achievement exist between pairs of SL and ELGM as well as SL and CEL. This implies that each of the ELGM and CEL is significantly more effective in enhancing basic science students' achievement than SL.

H02: There is no Significant Main Effect of Gender on Students' Achievement in Basic Science

Table 2 shows that there was no significant main effect of gender on students' achievement in basic science ($F_{(1,264)} = 0.010$, $p < 0.05$). This implies that gender had no significant main effect on students' post-test achievement mean score in basic science. Therefore, Hypothesis 2 is not rejected.

H03: There is no Significant Main Effect of FCIS on Students' Achievement in Basic Science

Table 2 indicates that there was a significant main effect of FCIS on students' achievement in basic science ($F_{(1,264)} = 4.08$, $p < 0.05$; partial $\eta^2 = 0.015$). Thus, the FCIS had a significant main effect on students' post-test achievement mean score in basic science and the effect size is 1.5%. Therefore, Hypothesis 3 is not accepted. In order to ascertain the groups' performances, EMM were calculated and outcomes are presented in Table 5.

Table 5

EMM of Post-Test Achievement Scores in Basic Science by FCIS Groups

Group	*N*	*Mean*	Std. error	95% confidence interval	
				Lower bound	Upper bound
1. Science-related	197	23.865[a]	0.408	23.061	24.668
2. Non-science related	80	22.184[a]	0.728	20.751	23.616

Note. [a]. Covariates appearing in the model were evaluated at pre-achievement score = 3.4152.

Table 5 reveals that science-related FCIS students had superior post-test basic science achievement mean score (23.87) to the non-science related (22.18). Thus, there was a better performance of the science-related FCIS students than the non-science related.

H04: There is no Significant Interaction Effect of Treatment and Gender on Students' Achievement in Basic Science

Table 2 indicates that no significant 2-way interaction effect of treatment and gender was observed on students' achievement in basic science ($F_{(2,264)} = 1.16$, $p < 0.05$). Therefore, Hypothesis 4 is not rejected.

H05: There is no Significant Interaction Effect of Treatment and FCIS on Students' Achievement in Basic Science

Table 2 shows that 2-way interaction effect of treatment and FCIS on students' achievement in basic science ($F_{(2,264)} = 1.05$, $p < 0.05$) was no significant. Therefore, hypothesis 5 is not rejected.

H06: There is no Significant Interaction Effect of Gender and FCIS on Students' Achievement in Basic Science

Table 2 reveals no significant 2-way interaction effect of gender and FCIS on students' achievement in basic science ($F_{(1,264)} = 1.17$, $p < 0.05$). Therefore, Hypothesis 6(a) is not rejected.

H07: There is no Significant Interaction Effect of Treatment, Gender, and FCIS on Students' Achievement in Basic Science.

Table 2 indicates that there was no significant 3-way interaction effect of treatment, gender, and FCIS on students' achievement in basic science ($F_{(2,264)} = 0.06$, $p > 0.05$). Therefore, Hypothesis 7 is not rejected.

Results

Effect of Treatment on Students' Achievement in Basic Science

This study revealed that SL and ELGM experiments had significant main effect on students' achievement in basic science. The ELGM proved superior to the CEL experiments due to its additional activities which enabled the students to investigate their predictions/extrapolations of results and discover other relationships among the experimental variables. For example, students in the ELGM group were made to discover the angle of incidence from the glancing angle and they were made to extrapolate and investigate the relationship between angles of incidence and reflection to angle 90^0. These were not included in the CEL experiments. This is in agreement with the finding of Dechsri, Jones, and Heikkinen (1998) that a Chemistry manual enriched with pictures or diagrams improved university students' achievement in the general Chemistry course than the Chemistry laboratory manual without pictures or diagrams enrichment.

Furthermore, the findings of this study revealed that both the ELGM experiments and CEL experiments enhanced students' achievement in basic science than the SL experiments. This is because basic computer proficiency is required to operate SL experiment and students needed some time to practice in order to gain mastery on the use of computer. Computer ability is not necessary for the students to conduct the ELGM and control/CEL. The finding negates existing findings which established effectiveness of the computer-simulated experiments over the conventional (expository) instructional strategy (Geban, Askar, & Özkan, 2010; Tüysüz, 2010; Kim, 2007). Also, it contradicts the observations of Batholomew, Oyedepo, and Yusuf (2011) and Huppert, Lomask, and Lazarowitz (2010) that SL experiments improved students' achievement in science than the hands-on laboratory experiments. It did not agree with the results of Pyatt and Sims (2007) that SL experiments produced higher achievement than hands-on laboratory experiments while the CEL experiments recorded least among high school students.

Effect of FCIS on Students' Achievement in Basic Science

The study indicated that FCIS had significant effect on students' achievement in basic science. Science-related FCIS improved students' achievement in basic science more than non-science related FCIS. This is because the belief that basic science will help in the realization of life ambition encouraged students with science-related FCIS to perform better than those with non-science related FCIS. This is in line with Odetoyinbo (2004) result that students' intended career contributed to JSIII students' achievement in Integrated Science in Oyo State. Also, it strengthens the observation by Osokoya (2003) that career aspiration and students' achievement in Chemistry were positively related.

Conclusions

This study revealed that SL and ELGM experiments are potent in making students to experience inquiry-based participatory scientific activities. Thus, SL experiment offers a viable alternative to the use of hands-on laboratory experiment in order to teach basic science effectively especially in schools where there are no functional science laboratories. However, schools with well-equipped laboratory could enrich their practical lessons through the use of the ELGM experiments.

FCIS propels students to do well in science subjects. This is evident in greater achievement in basic science of students in the science-related than those in the non-science related future career interest. SL and ELGM experiments provide discovery-oriented activities which arouse and sustain students' interest in and promote conceptual understanding in basic science. Therefore, the two modes of laboratory experiment are facilitative of improved students' achievement.

The SL and ELGM experiments are recommended to basic science teachers for teaching the practical components of the subject. This will encourage students to use their initiatives to conduct laboratory experiments, identify concepts, correct their misconceptions, and thereby construct knowledge while working in groups in order to enhance achievement in basic science.

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