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CONSTRUCTIONISM AND SENIOR SECONDARY STUDENTS' LEARNING ACHIEVEMENT IN SOLID GEOMETRY

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Abstract:
This study investigated the effects of Constructionist Class of Instructional (2CI) models on Solid Geometry Achievement (SGA) of Senior Secondary Class I (SSC1) students in Emohua Local Government Area (LGA) of Rivers State, Nigeria. The specific 2CI-models used in this study were Design-Based Learning (DBL) and Learning-While-Doing (LWD) instructional models. A quasi-experimental design was used. A total of 89 SSCI students took part in the study. Solid Geometry Achievement Test (SGAT) was used to measure student SGA. The KR-21 was used to determine the reliability of the SGAT and an index of 0.84 was obtained. The study was guided by two research questions and two hypotheses respectively. The descriptive statistic and Analysis of Covariance (ANCOVA) were used for data analysis. The study found that the 2CI-models advanced the SGLA of students over time. The DBL proved to be fairly superior to LWD over learning gain. The 2CI-models had a significant effect on the SGLA of the students. There was a significant main effect of 2CI-models over the Problem-based Learning (PbL) model on SGLA of SSC1 students. There was no significant difference between the mean SGLA scores of the male and the female students instructed using 2CI-models over PbL model. The study recommended among others the adoption of 2CI-models in teaching mathematics since it has been proven to aid students to own and apply their knowledge.

Keywords: constructionism, design-based learning, learning-while-doing, solid geometry achievement

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1. Introduction

The learning theory, constructionism was pioneered by Seymour Papert (Harel & Papert 1991). It builds on constructivism which was founded by Jean Piaget (Piaget, 1929, 1977). Constructionism posits that learning occurs as a result of the engagement of the learner in the construction of artifacts or products that can be shared (Harel & Papert, 1991; Papert, 1993, 1994). The use of pedagogical models based on constructionism focuses on creating a means of helping students to own and apply their knowledge. It is purported to develop novel skills in learners. The skills for citizenship, continuous learning, and career development are vital to the educational progress of learners in the 21st-century globalized world (Bray, 2010; Wagner, 2012). Mays (2015) stated that constructionism empowers the students to improve their knowledge through purposeful learning activities and exploration, collaboration, reflection and innovative design. This can be established through helping students to actively participate in the project/artifact design, development and completion aimed at solving a real-life problem.

Constructionism supports the active construction of knowledge by the learners; hence education should consist of the provision of opportunities for learners to engage in creative activities that catalyse this productive practice. The learner is the centre of education. The learners are guided to advance knowledge through active learning engagement, creative design, reflection, and exploration. The students learn social skills, respect, and collaboration (Gerver & Robinson, 2010, Kuh, Kinzie, Schuh, & Whitt, 2010; Bergmann & Sams 2012; Lough, 2014 Mays, 2015). Constructionism opines that learning occurs better when learners are engaged in constructing a sharable project or a meaningful product that they can think about. It based on the idea of learning by making projects (Papert & Harel 1991). Two types of construction are involved. When learners are engaged in the construction of physical projects, they concomitantly construct novel knowledge in their brains. This new knowledge then facilitates their capacity to physically build up more complex projects, creating a sort of ripple effect. The 2CI-models are therefore project-based.

Project-Based Learning (PBL), unlike a mere mathematics lesson, focuses first on the identification of the particular mathematical task to be performed. Then an artifact or project is developed to solve this problem. As a by-product of engagement in the development of this project, learners develop in-depth knowledge of complex problem-solving or critical thinking and of related concepts drawn from various subject areas in an authentic and engaging way (Lough 2014). To make active builders of knowledge, students are engaged in PBL activities. The explorative nature of PBL and the authentic engagement of students in project completion reinforce skills in problem-solving and enhance an in-depth understanding of what is learned (Han & Bhattacharya, 2001; Krauss & Boss, 2013). The Math by Doing (MbD), Open education, Child-centered education, Informal learning Design-Based Learning (DBL) and Learning While Doing (LWD) are some of the instructional models based on constructionism. This study is an attempt to explore the effectiveness of 2CI-models in the improvement of SGA of SSC1 students in Emohua LGA.

The efficacies of the 2CI-models in advancing student learning outcomes have been demonstrated in previous studies (Harel & Papert, 1991, Kafai *et al* 2008). Özdemir (2006) found that PBL enhanced students' geometry achievement and attitudes towards geometry respectively. Furthermore, the study specifically established that the improvement was in terms of aiding students to make their own models and handling real-life problems among others.

The exploration by Cervantes (2013) on the efficacy of PBL model on the reading and mathematics among learners also showed that students instructed with the PBL outperformed their non-PBL counterparts on a large majority of the grade reporting categories based on observed and adjusted scores for the outcome measures. This study showed that engagement of students in PBL had positive impacts on their academic achievement in mathematics and reading. Also, Bilgin, Karakuyu, and Ay (2014) investigated the effects of PBL model on the self-efficacy belief and learning achievement of undergraduates in science teaching and views of students about PBL. It was found that PBL model enhanced students learning achievement and self-efficacy. Most of the students who were taught using the PBL model had more positive views of PBL. A similar study by Özdemir, Yıldız, and Yıldız (2015) examined the effect of PBL on mathematical success and attitudes toward mathematics among 7th grade students. It was established that PBL was found more efficacious than the traditional methods for enhancing the students' mathematical achievements and positive attitude toward mathematics lessons. The PBL was more successful than the conventional methods of instruction for realizing the acquisition of the targeted level of knowledge of the rate, proportion and percentage unit.

Some other studies have also considered the effectiveness of PBL model respecting the sex of the learners. Konrad (2014) explored the efficacy of PBL in the improvement of the learning achievement and motivation of students in a remedial high school algebra classroom. A significant improvement was found in the attitude of students toward mathematics. A comparison of the prospective and retrospective assessment results indicated that 60 percent of the male and 75 percent of the female students improved in their post-test scores by 20% or more. The results of the male and female students followed a similar pattern in terms of motivation. No significant mean difference between the male and the female student over motivation in the algebra classroom. On the overall, the study established that the PBL model was a useful teaching tool for the motivation of learners. Similarly, Grady and Ibrahim (2014) explored the effect of PBL on the learning outcomes and perception of students. The student found that students instructed using PBL performed better than their counterparts instructed using the lecture method. However, there was no significant mean difference between the male and the female students over learning outcomes under conditions of the PBL model. The students preferred the PBL classes to lecture method and were more motivated in it. The 2CI-models used in this study were the DBL and the LWD models.

Design-Based Learning (DBL) combines engineering design and scientific inquiry in an effort to engage learners to reason scientifically through solving real-life tasks. This educational strategy engages the students in the gathering and application of theoretical knowledge and in finding solutions to design problems. The centre of DBL is the design of artifacts, systems, and solutions in a PBL environment (Kolodner, 2002; Lee & Breitenberg, 2010; Apedoe & Schunn, 2012). Learning While Doing (LWD) is an active strategy of education where participants undertake simultaneous roles of learning and teaching. Learners build their own knowledge, diverse styles and approaches are encouraged while tackling the project, and there are exploration and risk-taking. The LWD strategy involves collaboration, as learners work with professionals, inquiry/learning discussion is encouraged and learners engage in genuine, authentic real-world tasks among others (Tempel, 2007; Lough 2014).

2. Problem specification

The expertise of the mathematics teachers in the utilization of the 2CI-models to advance student mathematics learning outcomes is questionable. No wonder, Ogunkunle (2009) proved that school teachers were ineffective in the delivery of mathematics instructions in the schools in Port Harcourt. That is to say, if no attempt is made to alter this trend, the enhancement of the student learning achievement will be an effort in futility.

Several studies have been done and also advocated the application of the 2CI-models in the teaching of mathematics. However, the effectiveness of the 2CI-models in advancing student SGA in the senior secondary schools in Emohua LGA has not been carried out. To plug this gap in knowledge, the present study is an exploration of the effect of 2CI-models on the SGA of SSC1 students.

2.1 Aim and objectives of the study

This study is aimed at investigating the effectiveness of the 2CI-models in advancing the SGA of SSC1 students in Emohua LGA of Rivers State. The specific objectives of the study are to:

1) investigate the relative effectiveness of 2CI-models (DBL & LWD) over the Problem-based Learning (PbL) model in the achievement of senior secondary students in solid geometry.
2) compare the difference between the achievement of the male and the female senior secondary students taught solid geometry using 2CI-models over the PbL model.

2.2 Research questions

The following research questions guided the study:

1) What is the relative effectiveness of the 2CI-models over the PbL model with respect to the achievement of senior secondary students in solid geometry?

2) What is the difference between the mean achievement scores of male and female senior secondary students taught solid geometry using the 2CI-models over the PbL model?

2.3 Hypotheses

The following null hypotheses were tested at 0.05 level of significance:

H_{01}: There is no significant effect of the 2CI-models over the PbL model on the learning achievement of senior secondary students in solid geometry.

H_{02}: There is no significant difference between the respective mean learning achievement scores of male and female senior secondary students taught solid geometry using the 2CI-models over the PbL model.

3. Methodology

3.1 Research design

The study adopted the quasi-experimental design. The instructional model is the independent variable whereas solid geometry learning achievement is the dependent variable. The research design is symbolically illustrated in Table 1.

Table 1: Quasi-experimental research design

Group	Pre-test	Treatment	Post-test
E_1	O_1	X_{DBL}	O_2
E_2	O_1	X_{LWD}	O_2
C	O_1	X_{PbL}	O_2

Where:
O_1 = Pre-SGAT, O_2 = Post-SGAT
E_1 = Experimental group-1, X_{DBL} = Design-Based Learning (DBL)
E_2 = Experimental group-2, X_{LWD} = Learning While Doing (LWD)
C = Control group, X_{PbL} = Problem-based Learning (PbL)

3.2 Participants

A total of 2190 students constituted the population of the study (Rivers State Senior Secondary Schools Board, 2015). A total of 89 SSCI students participated in the study. Emohua LGA was purposively selected from the 23 LGAs in River State and it was used because of the availability of coeducational public senior secondary schools with a manageable number of students in each class among other criteria. Three senior secondary schools were purposively selected for participation. Only one arm of SSSI class was randomly selected for participation in each of the three schools. Two out of the three selected arms of SSSI classes in the three schools were randomly assigned to the experimental groups whereas the remaining one was assigned to the control group. The experimental group-1 had 29 students, the experimental group-2 had 30 students and the control group had 30 students.

3.3 Instrument

A validated 50-item instrument, Solid Geometry Achievement Test (SGAT) was used to quantify the students' learning achievement in solid geometry. The SGAT had multiple-choice questions/items with four options lettered A to D to be marked over 100 (i.e each correct option carries 2 marks). The reliability of the SGAT was established using the Kuder-Richardson, KR-21 reliability method to obtain an index of 0.84.

3.4 Experimental procedure

The Pre-SGAT and Post-SGAT were established using specially briefed teachers. The scripts from Pre-SGAT were retrieved prior to the beginning of the teaching by the teachers. The planning and development of the lessons for the experimental groups were done by the researchers. The teachers in the experimental group were trained on the practical and theoretical aspects of constructionism before the teaching commenced in all the groups.

A. Intervention group 1

The activities used in the project development phase of DBL model was adapted and modified from Apedoe, Ellefson, and Schunn (2012) and the characterization of activities were summarized in Table 2

Table 2: Summary of the key design activities using the DBL model

Learning cycle phase	Description of phase	Student activity	Type of activity
Create a design	A design is built based on previous understanding or experience	A scale of measurement is used by the student groups to attempt to design some real-life artifact	Group
Evaluate outcome	A decision is made on the functionality of a design based on specific necessities	The student groups endeavour to assess the result or outcome of their chosen project to ascertain whether it is working or not	Group
Generate reasons	Think through all the probable reasons behind the success or failure of the design is functioning well	The students individually or group or large class suggest ideas and think through their projects to find out reasons that led to the obtained result	Individual, group and class
Test idea	Systematically evaluate one of the ideas (reasons) brainstormed during the previous phase (generate reasons)	The student groups brainstorm of how to test ideas in order to link to geometrical-important properties.	Group
Analyze results	Explore the data obtained to find out whether the results support the previously tested ideas or not	The students collect data and record it to aid them in the construction of tables and graphs for result analysis	Individual, group

Generalize results	Confirm the existence of trends in the data collected	The results/projects are showcased by the students. This aids them to find vital structures in the data collected by the class.	Class (sharing group result)
Connect to big idea	Link the identified trends to an existing idea or theory in science. The technical idea is beneficial in advancing the performance of the earlier design	Using class discussion, the students share opinions to understand the Big Idea existing in the project	Class

B. Intervention group 2

The procedures used in the project development phase of LWD model was adapted and modified from Lough (2014) and the characterization of activities were summarized in Table 3.

Table 3: Summary of the project development activities using the LWD model

Project development phase	Description of phase	Student activity	Type of activity
Problem identification	The subtopic and related problem/project are selected	The student team confirms the subtopic and selects related problem. A local concern related to the subtopic is identified. Discussion starters are used for the problem identification of the. However, the solutions to the identified problem were not discussed at this point. Write down the problem in one sentence to establish focus.	Team task
Brainstorming	Brainstorm problem ideas	Many different possible ideas were generated. These ideas are listed on a poster. The students neither discuss nor evaluate any idea yet. All group members were encouraged to contribute ideas. Crazy ideas were allowed for the generation of more useful ideas.	Team task
Solution concept development	Develop a solution to selected problem/project	The student team developed a solution to selected problem/project. Discussion and evaluation of the solution ideas from the brainstorm list were established. Related ideas were grouped into solution concept. A plan for solution concept was created. This could be in form of	Team task

		a schematic diagram or logic flowchart.	
Project development	Project development	The student team collaborated to develop, test, revise, finalise and share finished project. They kept a project journal in a notebook. The developed project prototype was tested. Some necessary revisions were made and the project also re-tested. The students finalised project prototype, and share the project with others in a presentation	Team task

C. Control group

The teacher and student activities at each stage of the PbL are summarised in Table 4:

Table 4: Summary of the key activities using the PbL model

Strategic components	Instruction	Student activity	Type of activity
Study	The students were made to understand the specific problem as well as the needs	Keen attention is paid by the students as the teacher explains concepts.	Class
Planning	The teacher discloses the procedure that leads to the solution of the mathematical task	The students jotted down by the students while paying apt attention to the teacher who explained the solution procedures.	Class
Execution	The teacher explains each step used to obtain the solution while solving the problem the problem	The current mathematical task is tackled by the students with the teacher. They also tried to ascertain the actions taken at each stage of the problem-solving episode.	Class
Evaluation	The evaluation of the solution process is done by the teacher. The students are also aided by the teacher to reassess their own solution steps too.	The solution procedures or steps were validated by the students to be double sure no wrong step was taken at the process of execution of the solution steps	Class
Development	The class teacher applied the solution process to solve related real-life problems.	With the teacher as a guide, the students applied various learned procedures from the lesson in an attempt to solve other real-life problems related to the topic learned	Class

3.5 Data analysis

Descriptive statistic was used to answer the research questions whereas Analysis of Covariance (ANCOVA) was used to test the hypotheses at 0.05 level of significance.

4. Results

Table 5: Descriptive statistic on the learning gain of the student groups taught using SCI-models and PbL model respectively

		DBL (N=29)		LWD (N=30)		PbL (N=30)	
		Statistic	Std. Error	Statistic	Std. Error	Statistic	Std. Error
Mean		30.28	2.11	30.13	1.80	21.87	1.92
95% CI for Mean	Lower Bound	25.95		26.45		17.93	
	Upper Bound	34.60		33.82		25.80	
Median		30.00		29.00		24.00	
Std. Deviation		11.36		9.87		10.54	
Minimum		12.00		6.00		-2.00	
Maximum		54.00		44.00		40.00	

Note: CI = Confidence interval

Table 5 shows that the Mean Learning Gain (MLG) of students instructed using the DBL model was 30.28 ± 11.36 and the 95% CI moved from 25.95 to 34.60. The MLG of the students taught using LWD model was 30.13 ± 9.87 and the 95% CI moved from 26.45 to 33.82. The MLG of students instructed using PbL was 21.87 ± 10.54 and the 95% CI moved from 17.93 to 25.80. The above data was further presented on box plot as shown in Figure 1 below.

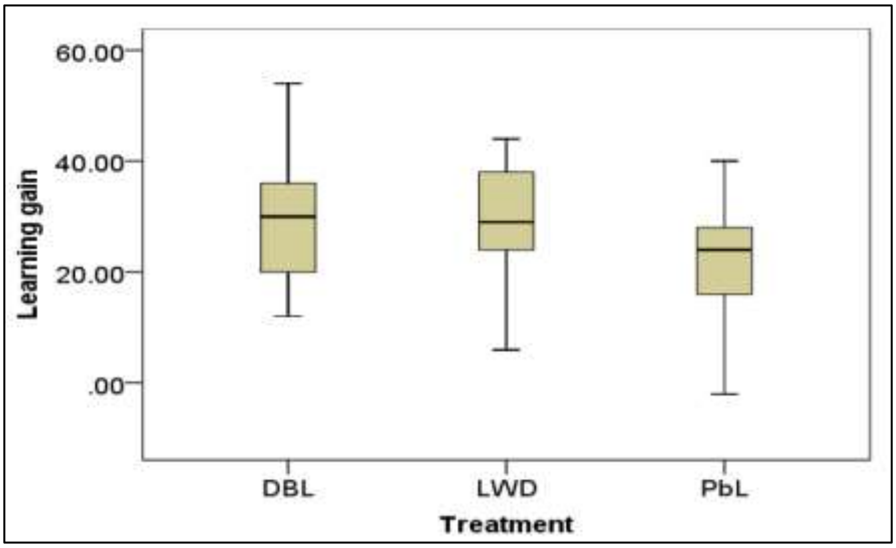

Figure 1: Box plot

The clustered box plots of learning gain as categorised by the treatments were plotted in Figure 1 above. The figure showed no outlier. The boxplot contains mid 50 percent and each whisker represents upper and lower 25 percent of the cases. Therefore, the lower 50% of the gain in learning among students instructed with the DBL model ranged between 12.00 and 30.00 whereas the upper 50% ranged between 30.00 and 54.00.

The lower 50% of the gain in learning among students instructed using the LWD model ranged between 6.00 and 29.00 whereas the upper 50% ranged between 29.00 and 44.00, while the lower 50% of the gain in learning among students instructed using the PbL model ranged between -2.00 and 24.00 whereas the upper 50% ranged between 24.00 and 40.00.

Table 6: Descriptive statistic on the learning gain of the male and female student groups instructed with constructionist instructional models and PbL model respectively

			DBL		**LWD**		**PbL**	
Sex			**Statistic**	**Std. Error**	**Statistic**	**Std. Error**	**Statistic**	**Std. Error**
Male	Mean		33.50	2.44	31.22	1.74	18.83	3.66
	95% CI for Mean	Lower Bound	28.30		27.55		10.77	
		Upper Bound	38.70		34.90		26.90	
	Median		32.00		29.00		22.00	
	Std. Deviation		9.76		7.39		12.69	
	Minimum		20.00		20.00		-2.00	
	Maximum		54.00		44.00		38.00	
Female	Mean		26.31	3.41	28.50	3.73	23.89	2.04
	95% CI for Mean	Lower Bound	18.88		20.28		19.59	
		Upper Bound	33.74		36.72		28.18	
	Median		20.00		29.00		25.00	
	Std. Deviation		12.30		12.94		8.64	
	Minimum		12.00		6.00		4.00	
	Maximum		48.00		44.00		40.00	

Table 6 shows that the MLG of the male students instructed using DBL model was 33.50 $\pm$ 9.76 and their 95% CI moved from 28.30 to 38.70. The MLG of the male students taught using LWD model was 31.22 $\pm$ 7.39 and their 95% CI moved from 27.55 to 34.90 whereas the MLG of the male students instructed using PbL model was 18.83 $\pm$ 12.69. The 95% CI moved from 10.77 to 26.90. However, Table 6 further shows that the MLG of the female students taught using DBL model was 26.31 $\pm$ 12.30. The 95% CI moved from 18.88 to 33.74. The MLG of female students taught using LWD model was 28.50 $\pm$ 12.94. The 95% CI moved from 20.28 to 36.72 whereas the MLG of female students taught using PbL was 23.89 $\pm$ 8.64. The 95% CI moved from 19.59 to 28.18. The above data was further presented on clustered box plot as shown in Figure 2 below.

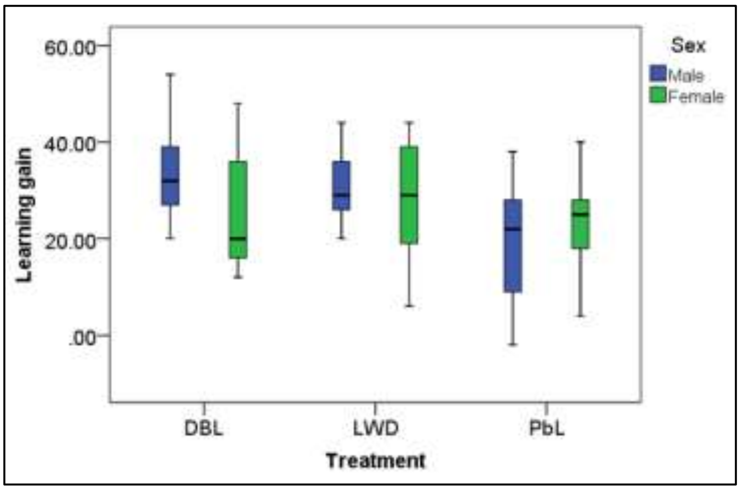

Figure 2: Clustered box plot based on sex and tretment

The clustered box plots of learning gain as categorised by the treatment and sex were plotted in Figure 2 above. The figure shows that there was no outlier. The lower 50% of the gain in learning among male students instructed using the DBL model ranged between 20.00 and 32.00 whereas the upper 50% ranged between 32.00 and 54.00 while the lower 50% of the gain in learning among female students instructed using the DBL model ranged between 12.00 and 20.00 whereas the upper 50% ranged between 20.00 and 48.00. The lower 50% of the gain in learning among the male students instructed using the LWD model ranged between 20.00 and 29.00 whereas the upper 50% ranged between 29.00 and 44.00 while the lower 50% of the gain in learning among the female students instructed using the LWD model ranged between 6.00 and 29.00 whereas the upper 50% ranged between 29.00 and 44.00. The lower 50% of the gain in learning among the male students who were taught using the PbL model ranged between -2.00 and 22.00 whereas the upper 50% ranged between 22.00 and 38.00 while the lower 50% of the learning gain of female students who were taught using the PbL model ranged between 4.00 and 25.00 whereas the upper 50% ranged between 25.00 and 40.00.

Table 7: Summary of ANCOVA results on the effect of sex on the learning achievement of students instructed using the 2CI-models over PbL

Source	SS	df	MS	F	p-value	η^2
Pre-SGAT	17.522	1	17.522	.312	.578	.004
Treatment	2235.489	2	1117.745	19.915	.000	.322
Sex	1.333	1	1.333	.024	.878	.000
Error	4714.668	84	56.127			
Total	276832.000	89				
Corrected Total	7056.719	88				

Note: SS = Sum of Squares, df = Degree of Freedom, MS = Mean Square

Table 6 shows that there was a significant effect of the 2CI-models over the PbL model on the SGA of SSC1 students (F1, 84=19.915, p=.000, Partial eta-squared =.322). This led to the rejection of the null hypothesis one at .05 alpha level.

The result further shows that there was no significant difference between the respective mean learning achievement scores of male and female senior secondary students taught solid geometry using the 2CI-models over the PbL model (F1, 84=.024, p=.878, Partial eta-squared =.000). The null hypothesis two was thus upheld at .05 level of significance

5. Discussion of Findings

The findings are discussed in the following subheadings:

5.1 The 2CI-models and student SGA

The result as reflected in Table 5 indicated that the students instructed using the 2CI-models outperformed those instructed using the PbL model. Precisely, the findings established that students instructed using DBL model and those instructed using LWD model respectively had learning gains of 8.41 and 8.26 more than those instructed using the PbL model. This showed that the 2CI-models were capable of improving the learning achievement of the students in solid geometry. The box plot as presented in Figure 1 likewise indicated that the interval of the upper 50% of the learning gain of students instructed using the DBL model was the highest when compared to that of those instructed using the LWD and PbL models respectively. When put to the statistical test, the result in Table 7 showed that there was a significant effect of the constructionist class of instructional models over the PbL model on the learning achievement of senior secondary students in solid geometry. The null hypothesis one was rejected at .05 alpha level. The above finding is in agreement with a previous finding of Özdemir, Yıldız, and Yıldız (2015) which examined the effect of Project-Based Learning (PBL) on the mathematical success and attitudes toward Mathematics among 7th-grade students and established among other findings that PBL was more efficacious than the conventional methods for fostering students' mathematical achievements and positive attitude toward Mathematics lessons.

5.2 The 2CI-models and sex associated SGA among students

The result as reflected in Table 6 showed that the male students instructed using the 2CI-models gained more than their counterparts instructed using the PbL model. Specifically, the male students who were taught using the DBL model gained more than their male counterparts who were taught using the PbL model with a learning gain of 14.67 whereas the male student group taught using the LWD model gained more than their male counterparts taught using the PbL model with a MLG of 12.39. Similarly, the female students taught using the DBL and those taught using the LWD model gained more than their female counterparts who were taught using the PbL model with learning gains of 2.42 and 4.61 respectively. The box plot as presented in Figure 2 also showed that the interval of the upper 50% of the learning gain of female students who were taught using the DBL model was the highest in comparison with others. However, when put to the statistical test, the result in Table 7 showed that there was no significant difference between the respective mean learning achievement scores of male and female students taught solid geometry using the constructionist class of instructional models over the PbL model. The null hypothesis two was thus upheld at .05 level of significance. This finding is in agreement with an earlier study by Grady and Ibrahim (2014) which investigated the effect of the Project-Based Learning model on students' learning outcomes and perception. The finding among other results established that there were no significant sex differences in the learning outcomes between the male and the female students who were taught using the PBL model.

6. Conclusion

The 2CI-models have proven to be significantly effective in the improvement of the SGA of SSC1 students. The DBL model proved to be fairly superior to the LWD model in terms of the learning gain of the students. The experiment was however beneficial to all groups of students. In more specific terms, the male students who were taught using the DBL model benefited most when compared to their counterparts who were taught using the LWD and the PbL models. The female students instructed with the LWD model benefited more than the female students instructed using the DBL model and those taught using the PbL model. However, there was no significant difference between the respective mean learning achievement scores of male and female students taught solid geometry using the constructionist class of instructional models over the PbL model. The implication of the established findings is that; since the 2CI-models were shown to be successful in advancing the learning achievement of the students in solid geometry, stakeholders in Mathematics education should endeavour to promote the adoption of these innovative learning models in our Mathematics classrooms to promote the acquisition of critical thinking and problem-solving skills.

6.1 Recommendations

Based on the findings of the study the following recommendations were made:

1) Mathematics teachers should adopt 2CI-models in the Mathematics classroom. This is because the 2CI-models help in developing means of aiding the students to own and apply their knowledge, as well as in instilling novel skills in the learners.
2) The Mathematics teachers should engage the students, irrespective of their sex in project development episodes to improve their complex problem-solving, continuous learning and career development skills which are vital for their success in the 21st century.

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