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# Effect of Mathematics-by-Design model on junior secondary student performance in solid geometry

Sylvia Chienyenwa Oringanje[1], Nduka Wonu[2]

[1]*Department of Curriculum Studies and Instructional Technology, Ignatius Ajuru University of Education, Port Harcourt, Nigeria.*

[2]*Department of Mathematics/Statistics, Ignatius Ajuru University of Education, Port Harcourt, Nigeria*

*Correspondence: E-mail: wonu.nduka@iaue.edu.ng*

***Abstract*** - *This study investigated the effect of Mathematics-by-Design (MbD) on the public junior secondary student performance in solid geometry in Obio/Akpor Local Government Area of Rivers State. A total of 102 Junior Secondary Class one (JSC1) students was used. Simple random sampling technique was used to select two junior secondary schools from the Local Government Area and the purposive sampling technique was used to select junior secondary classes composed of two intact classes from the schools. Only those who participated in the prospective assessment were used for the study. Four research questions were answered while four hypotheses were tested in the study. Solid Geometry Performance Test (SGPT) was the instrument used to collect data on student pre-test and post-test. The test-retest method was used to determine the reliability of SGPT to obtain an index of 0.81. Mean, standard deviation and Analysis of Covariance (ANCOVA) were used for data analysis. It was found that MbD significantly improved the performance of the students in solid geometry over time. Sex and ability groupings respectively had no significant effect on the performance of students who were taught using MbD. It was recommended among others that Mathematics teachers should endeavour to make the teaching of solid geometry more practical oriented by using an instructional strategy such as the MbD.*

**Keywords —** *Mathematics, Design, Solid geometry, Performance, Ability*

## I. INTRODUCTION

Geometry is an important component of the secondary school Mathematics curriculum in Nigeria. In the junior secondary curriculum in Mathematics, geometry has been accorded a broad theme recognition that cuts the three levels of the junior secondary school. Basically, school geometry is divided into two, namely plane and solid geometry. Solid geometry, 3-Dimensional (3D) shapes have three dimensions: lengths, width, and height/depth [8]. Solid geometry and its concepts are common tools and phenomenon in human life probably because they deal with shapes that occupy space. Every household item has one form or combination of geometric shapes. Despite the fact that geometry is highly embedded in human activities, property, and belongings, students in secondary school still perceive it as a difficult theme to learn. This explains the overflow of research on students learning of solid geometry focusing on the ability to translate between 3D solid and their 2-Dimensional (2D) representations [9].

A thorough exposition to solid geometry taking cognizance of the idea of transformation at the secondary school level is capable of enhancing the interest of students, igniting their passion towards science and improve their academic performance which is what students have learned and it is usually measured through assessment like performance assessment. Solid geometry in mensuration involving multiple dimensional objects is embedded in the junior secondary Mathematics curriculum [8]. It is expected of Mathematics teachers to employ appropriate instructional models to achieve set curriculum objectives. There is no doubt that the world over is in search of research-based instructional models to reduce the abstraction in Mathematics. This study is an attempt to improve the quality of instruction in Mathematics in particular and Mathematics education in general. A good foundation of solid geometry among secondary school students perhaps will impact on their further studies. It was therefore pertinent to conduct this study to ascertain the efficacy of Mathematics-by-Design (MbD) in enhancing the junior secondary student performance in solid geometry. In order to reverse the trend, teaching with innovative instructional models becomes inevitable in an attempt to improve student learning outcomes. Some researchers have tried to explore the efficacy of several innovative instructional models to enhance student learning outcomes in geometry in Rivers State ([19], [20], [18], [21]).

Mathematics-by-Design has been advocated at the secondary school level in form of Design-Based Learning (DBL). The DBL when applied in a solid geometry lesson, allows the students to identify and apply theoretical knowledge while finding solutions to their design task [17]. This is based on the fact that the teacher is central in the business of classroom curriculum implementation. The need to adopt student-centered learning model that allows the teacher to play the role a facilitator by helping the students to become independent thinkers through real-life problem-solving exercises. The context could be a Mathematics laboratory. Engaging students in a real-life problem-solving in a Mathematics laboratory is helpful because it is a place where students learn and explore the mathematical concept and verify Mathematics facts and theorems through a variety of activities using different materials [11].

Mathematics-by-Design is a systematic approach to teaching and learning Mathematics that comprises of five teacher's moves such as asking, imagining, planning, creating and improving [5]. The MbD is a form of DBL model that engages the students to explore the pattern in mathematical concepts and operations in a design setting. It is an instructional model that requires the teacher to ask relevant questions to establish the gap between what has been taught and what has been learned. The teacher also imagines how to develop an instructional approach that will meet the needs of the students and then draw a plan towards it. The teacher now creates an object that will serve as instructional material including realia and models with the aim of improving the students understanding and performance in the subject. For example, in a geometry lesson, the teacher can set up the experiment of proof of geometrical fact using models of different geometric shapes and ask the students to observe and do them; record and interpret results in their own way. This strategy helps to make the students independent thinkers. The MbD is a form of Project-Based Learning (PBL) model that enables the students to learn what they need to learn in a just-in-time fashion while trying something [1]. [2] emphasized that DBL is a unique type of PBL. Students engaged in DBL are involved in developing, building and assessing a designed product. It is an effective strategy for education that is centred on the design based problem-solving framework used in PBL. Like in the PBL, under MbD, students are made to work in a small group while trying to solve the design problem in Mathematics during project development.

Mathematics-by-Design allows meaningful learning and real-life experience in the classroom setting by involving the students' head, heart, and hand as well as allow that transfer of information and skills. It is an activity-based teaching and learning process which helps the students to learn the content deeply and simultaneously to develop the higher-order problem-solving skills required to unravel the solution to complex Mathematics problem. It is also closely related to the Constructionist/Learning-While-Doing (C/LWD) model [7], [18]. Here, students are made to identify and apply theoretical knowledge while finding solutions to their design task as they get involved in doing or in seeing something done. The students learn the content and the process of unravelling the solution of the prototypical design of mathematical problems. This form of teaching and learning requires the teacher to use designed models and realia in Mathematics instruction. In geometry lessons, net of solid can be designed and the respective faces of the solid will be used to solve problems on volume/capacity and space occupied by the solid. As a form of PBL, Mathematics-by-Design encourages students to study individually or in a group for a certain time with active participation to reach a specific product or result. The approach encourages much more than telling by the teaching and much more than listening to the students. This instructional model can attract unwilling students and create a learning environment where students with different abilities can be more equal to each other [13]. The PBL in Mathematics, otherwise, MbD also encourages individual students to strengthen their learning, pull meaning from their experience and to share learning through collaboration.

**Problem specification**

It is no longer news of the recurring shocker as the West African Examination Council (WAEC) announces the general poor performance of students in Mathematics. This is against the fact that sound knowledge of Mathematics is very strategic in the scientific and technological development of any nation. Despite its importance, secondary students still perform poorly in both external and internal Mathematics examinations. As a component of Mathematics, geometry shares in the poorly written part of the subject. [16] WAEC chief examiners report has highlighted confusion on the plane and solid shapes; and poor knowledge on the rubrics of construction, among others, as some of the observations. This worrisome trend has provoked the curiosity of many researchers to search for a solution to poor performance in Mathematics among secondary school students. The question is: what effect does MbD have on junior secondary student performance in solid geometry in Obio/Akpor Local Government Area of Rivers State?

**Aim and Objectives of the study**

The main aim of the study is to establish the efficacy of Mathematics-by-Design (MbD) on the solid geometry performance of junior secondary class 1 students. The objectives of the study are to:

1. determine the difference between the learning performance mean score of students in public junior secondary schools taught solid geometry using MbD and those taught using problem-solving strategy.
2. ascertain the mean difference between the learning performance mean scores of the male and the female students in public junior secondary schools taught solid geometry using MbD.
3. determine the difference between the learning performance mean scores of high and low ability student groupings in public junior secondary schools taught solid geometry using MbD.

**Research questions**

The following Research Questions (RQs) guided the study:

$RQ_1$: What is the difference between the performance mean scores of students in public junior secondary schools taught solid geometry using MbD and those taught using Problem-solving strategy?

$RQ_2$: What is the difference between the performance mean scores of the male and the female students in public junior secondary schools taught solid geometry using MbD?

$RQ_3$: What is the difference between the performance mean scores of high and low ability student groupings in public junior secondary schools taught solid geometry using MbD?

**Research hypotheses**

The following research hypotheses guided the study:

**$Ho_1$:** There is no significant difference between the performance mean score of students in public junior secondary schools taught solid geometry using MbD and those taught using problem-solving learning strategy.

**$Ho_2$:** There is no significant difference between the performance mean scores of the male and the female students in public junior secondary schools taught solid geometry using MbD.

**$Ho_3$:** There is no significant difference between the performance of high and low ability student groupings in public junior secondary schools taught solid geometry using MbD.

## METHODS AND MATERIALS

**Design:** The study adopted the pretest-posttest non-randomized quasi-experimental research design. The study was carried out in Obio /Akpor Local Government of Rivers State.

**Participants**: A total of 102 JSC1 students took part in this study. Two public junior secondary schools out of 23 public secondary schools in the study area were selected. Purposive sampling technique was used to select the two co-educational schools in which 102 students from the two intact classes were sampled using a random sampling technique. Fifty (50) students formed the experimental whereas 52 students formed the control group. Only the students who participated in the pretest exercise were permitted to participate in the posttest.

**Instrument for data collection**: The instrument for data collection was Solid Geometry Performance Test (SGPT). The instrument was validated by two experts in Mathematics Education. Their contributions, comments, and corrections helped in modifying the instrument. Test-retest method was used to ascertain the reliability of SGPT to obtain a coefficient of 0.81.

**Data collection**: The experimental group was taught solid geometry using Mathematics-by-Design (MbD) whereas the control group was taught solid geometry using problem-solving strategy. Pretest and posttest were administered to both groups and retrieved for analysis.

**Data analysis**: The collected data were analyzed using mean, standard deviation and Analysis of Covariance (ANCOVA).

## RESULTS

**Table 1A: Summary of Pre-SGPT, Post-SGPT, Learning Gain and ANCOVA on the performance scores of students taught solid geometry using MbD and those taught using Problem-Solving Strategy (PSS)**

| | | Pre-SGPT | | Post-SGPT | | Gain | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Model | N | Mean | SD | Mean | SD | Mean | SD | $F_{(1,99)}$ | p-value | $\eta^2$ |
| MbD | 52 | 38.77 | 12.26 | 61.85 | 9.03 | 23.08 | 15.20 | 12.576 | .001 | .113 |
| PSS | 50 | 40.80 | 13.23 | 55.20 | 11.68 | 14.40 | 12.84 | | | |

**Table 1B: Descriptive statistic on the learning gain of the student groups taught using MbD model and PSS respectively**

| | | MbD Statistic | Std. Error | PSS Statistic | Std. Error |
|---|---|---|---|---|---|
| Mean | | 23.08 | 2.11 | 14.40 | 1.82 |
| 95% CI | Lower Bound | 18.84 | | 10.75 | |
| | Upper Bound | 27.31 | | 18.05 | |
| Median | | 24.00 | | 12.00 | |
| Std. Deviation | | 15.20 | | 12.84 | |
| Minimum | | -12.00 | | -12.00 | |
| Maximum | | 64.00 | | 40.00 | |

***Key: CI= Confidence Interval for Mean***

Part A of Table 1 shows the summary of the mean Pre-SGPT, Post-SGPT and mean learning gain scores of students taught solid geometry using MbD and those taught using PSS. It shows that the students taught using the MbD had Pre-SGPT mean score of 38.77±12.26, their Post-SGPT mean score was 61.85±9.03 whereas their SGPT mean gain was 23.08±15.20. The students taught using the PSS had Pre-SGPT mean score of 40.80±13.23, their Post-SGPT mean score was 55.20±11.68 whereas their SGPT mean gain was 14.40±12.84. It shows that there is a significant mean difference between the performance score of students in public junior secondary schools taught solid geometry using Mathematics-by-Design and those taught using Problem-solving Strategy ($F_{1, 99}$=12.576, p=.001, $\eta^2$ =.113). The null hypothesis one was rejected at .05 alpha level.

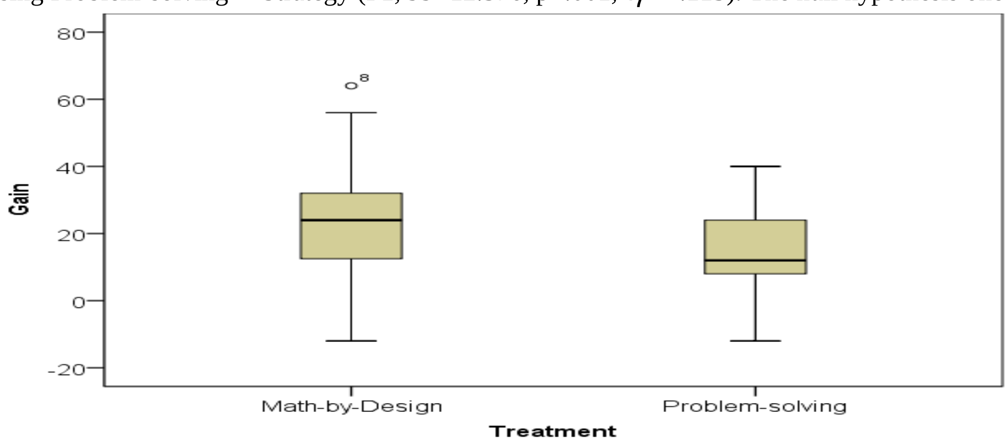


**Figure. 1: Boxplot**

The results in Part B of Table 1 and Figure 1 show further descriptive statistics and a clustered boxplot of learning gain of the students based on the treatments respectively. There was an outlier in the score of the group of students taught using MbD. A whisker of a boxplot signifies upper and lower 25% of the cases contained in the mid 50%. Therefore, the lower half of the learning gain of the students taught using MbD model lies between -12.00 and 24.00 whereas the upper half lies between 24.00 and 64.00. The lower half of the learning gain among students taught using PSS lies between -12.00 and 12.00 whereas the upper half lies between 12.00 and 40.00.

**Table 2A: Summary of Pre-SGPT, Post-SGPT, Learning Gain and ANCOVA on the performance scores of the male and the female students taught solid geometry using MbD**

| | | Pre-SGPT | | Post-SGPT | | Gain | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sex** | **N** | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** | $F_{(1,49)}$ | **p-value** | $\eta^2$ |
| Male | 29 | 43.45 | 11.75 | 60.72 | 8.09 | 17.28 | 12.46 | 1.251 | .269 | .025 |
| Female | 23 | 32.87 | 10.37 | 63.26 | 10.10 | 30.39 | 15.43 | | | |

**Table 2B: Descriptive statistic on the learning gain of the student group taught using MbD model based on sex**

| | | Male | | Female | |
|---|---|---|---|---|---|
| | | **Statistic** | **Std. Error** | **Statistic** | **Std. Error** |
| Mean | | 17.28 | 2.31 | 30.39 | 3.22 |
| 95% CI | Lower Bound | 12.54 | | 23.72 | |
| | Upper Bound | 22.01 | | 37.06 | |
| Median | | 16.00 | | 31.00 | |
| Std. Deviation | | 12.46 | | 15.43 | |
| Minimum | | -12.00 | | 0.00 | |
| Maximum | | 36.00 | | 64.00 | |

The result in Part A of Table 2 shows the summary of Pre-SGPT, Post-SGPT and Mean learning gain of the male and the female students taught solid geometry using MbD. It shows that the male students taught using the MbD had Pre-SGPT mean score of 43.45±11.75, their Post-SGPT mean score was 60.72±8.09 whereas their SGPT mean gain was 17.28±12.46. It shows that the female students taught using the MbD had Pre-SGPT mean score of 32.87±10.37, their Post-SGPT mean score was 63.26±10.10 whereas their SGPT mean gain was 30.39±15.43. It shows that there is no significant difference between the learning performance mean scores of the male and female students in public junior secondary schools taught solid geometry using Mathematics by design (F1, 49=1.251, p=.269, $\eta^2$ =.025). The null hypothesis two was retained at .05 alpha level.

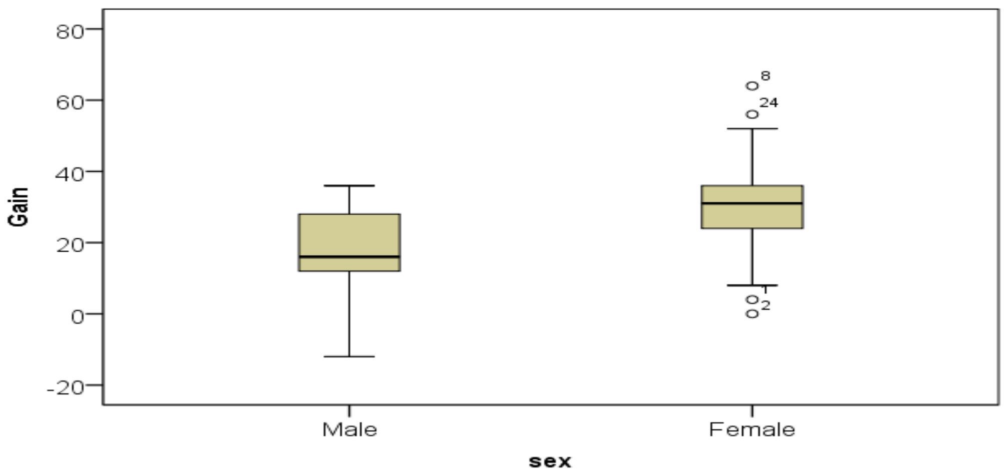


**Fig. 1: Boxplot**

The results in Part B of Table 2 and Figure 2 show further descriptive statistics and a clustered boxplot of the learning gain of the students based on sex respectively. There were outliers in the scores of the female students taught using MbD. The lower half of the learning gain of the male students taught using MbD model lies between -12.00 and 16.00 whereas the upper half lies between 16.00 and 36.00. The lower half of the learning gain among female students taught using PSS lies between 0.00 and 31.06 whereas the upper half lies between 31.06 and 64.00.

**Table 3A: Descriptive Statistics and ANCOVA on the performance scores of the high and low ability students taught solid geometry using MbD**

| | | Pre-SGPT | | Post-SGPT | | Gain | | $F_{(1,49)}$ | p-value | $\eta^2$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **Ability** | **N** | **Mean** | **SD** | **Mean** | **SD** | **Mean** | **SD** | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Low | 25 | 29.12 | 7.07 | 61.60 | 9.21 | 32.48 | 12.28 | .068 | .795 | .001 |
| High | 27 | 47.70 | 8.73 | 62.07 | 9.04 | 14.37 | 12.27 | | | |

**Table 3B: Descriptive statistic on the learning gain of the student group taught using MbD model based on ability grouping**

| | | Low ability | | High ability | |
|---|---|---|---|---|---|
| | | **Statistic** | **Std. Error** | **Statistic** | **Std. Error** |
| Mean | | 32.48 | 2.46 | 14.37 | 2.36 |
| 95% CI | Lower Bound | 27.41 | | 9.52 | |
| | Upper Bound | 37.55 | | 19.22 | |
| Median | | 32.00 | | 16.00 | |
| Std. Deviation | | 12.28 | | 12.27 | |
| Minimum | | 12.00 | | -12.00 | |
| Maximum | | 64.00 | | 32.00 | |

Part A of Table 3 shows the summary of Pre-SGPT, Post-SGPT and Mean learning gain of the high and low ability students taught solid geometry using MbD. It shows that the low ability students taught using the MbD had Pre-SGPT mean score of 29.12±7.07, their Post-SGPT mean score was 61.60±9.21 whereas their SGPT mean gain was 32.48±12.28. It shows that the high ability students taught using the MbD had Pre-SGPT mean score of 47.70±8.73, their Post-SGPT mean score was 62.07±9.04 whereas their SGPT mean gain was 14.37±12.27. It shows that there is no significant mean difference between the performance of high and low ability student groupings in public junior secondary schools taught using Mathematics by-Design ($F_{1, 49}$=.068, p=.795, $\eta^2$ =.001). The null hypothesis three was retained at .05 alpha level.

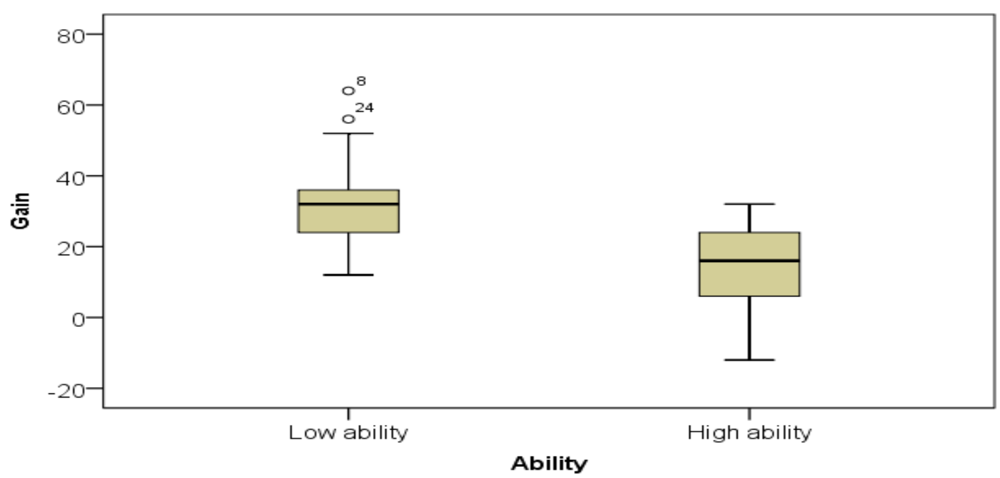


**Fig. 2: Boxplot**

The results in Part B of Table 3 and Figure 3 show further descriptive statistics and a clustered boxplot of the learning gain of the students based on ability groupings respectively. There were outliers in the scores of the low ability student group taught using MbD. The lower half of the learning gain of the low ability students taught using MbD model lies between 12.00 and 32.00 whereas the upper half lies between 32.00 and 64.00. The lower half of the learning gain among high ability students taught using PSS lies between -12.00 and 16.00 whereas the upper half lies between 16.00 and 32.00

## DISCUSSION

The findings were discussed under the following subheadings:

### Mathematics-by-Design and the performance of students in solid geometry

The result in Part A of Table 1 showed that the students instructed using the MbD outperformed those taught using the PSS over learning gain in solid geometry with a mean gain difference of 8.68. A closer peek at Table 1 showed that the students taught using the PSS outperformed those taught using MbD over the Pre-SGPT. The trend was changed in the Post-SGPT where students taught using the MbD outperformed those taught using PSS with a mean difference of 6.65. The result of ANCOVA showed that there was a significant mean difference between the performance score of students in public junior secondary schools taught solid geometry using Mathematics-by-Design and those taught using problem-solving strategy (F1, 99=12.576, p=.001, $\eta^2$=.113). The null hypothesis one was rejected at .05 alpha level. The present finding is consistent with an earlier finding by [6], [9] and [10] which established that teaching intervention involving practical demonstrations or instructional model significantly enhance students geometric thinking and achievement in solid geometry better than the conventional method.

### Sex-associated solid geometry performance and MbD

The result from Part A of Table 2 showed that the female students taught using MbD performed better than their male counterparts in the same group with a learning gain of 13.11. This showed that the experiment was more beneficial to female students. It also worthy of note that the female students performed lower than the male students in the Pre-SGPT and not in the Post-SGPT. The ANCOVA result showed that there was no significant difference between the learning performance mean scores of the male and female students in public junior secondary schools taught solid geometry using Mathematics by design (F1, 49=1.251, p=.269, $\eta^2$=.025). The null hypothesis two was retained at .05 alpha level. The present finding is inconsistent with an earlier finding by [4] that there was a statically significant difference between students' post-test scores in terms of gender, favoring females over males. However, [20] has established in their study that there is no significant difference between the respective mean learning achievement scores of the male and the female students taught solid geometry using the TfU instructional model over the conventional method.

### Student ability-associated solid geometry performance and MbD

The result from Part A of Table 3 shows that the students taught with MbD in the low ability group had higher learning gain than their counterparts in the same group with a mean difference of 18.11. A closer peek at the table shows that the students with high ability outperformed those with low ability in terms of Pre-SGPT and Post-SGPT with mean differences of 18.58 and 0.47 respectively. The experiment appears to be more beneficial to the students of low ability grouping because of the tremendous rise in their score in the Post-SGPT learning to the higher gain. The result of ANCOVA showed that there is no significant mean difference between the performance of high and low ability student groupings in public junior secondary schools taught using Mathematics by-Design (F1, 49=.068, p=.795, $\eta^2$ = .001). The null hypothesis three was retained at .05 alpha level. The present finding is consistent with earlier findings from [3], [14], [15] which established that students' ability measured in terms of interest and retention in Mathematics and geometry are positively and significantly related to students' academic achievement. Their finding further showed the effect of teaching methods on students' achievement, interest, and retention in Mathematics as they all relate positively.

## CONCLUSION

It has been established that junior secondary students taught solid geometry using Mathematics-by-Design learning model realised higher learning gain or improved more than those taught using the problem-solving strategy and that the female students taught using MbD attained higher learning gain or improvement more than the male students who were also taught using the same model. Although the female had slightly higher learning gain, this did not make much difference in the overall performance. The low ability group instructed using MbD had higher learning gain or improvement in learning more than the high ability group counterparts. The MbD is very effective in improving the solid geometry learning outcome of junior secondary students irrespective of their mathematical abilities. Therefore, adequate and appropriate instructional intervention strategy make every student to be carried along in the class as shown by no significant mean difference between the performance of the high and low ability student groupings in public junior secondary schools taught using MbD.

## RECOMMENDATIONS

Based on the findings of this study the following recommendations were made;

1. Mathematics teachers should endeavor to make the teaching of solid geometry more practical oriented using instructional strategy such as the Math-by-Design model. They should try to provide the locally made materials that

could enhance the design of solid geometric shapes in Mathematics and also guide the students in creating models themselves.

2. Mathematics teachers should not be gender-bias when teaching some practical aspects of Mathematics and geometry especially against the female sex, but they should encourage the female students in as much as the male students.
3. Stakeholders in education should provide relevant learning resources and build Mathematics laboratory that can be used to improve the performance of low ability students or those with a poor background in Mathematics.

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