IEJME OPEN ACCESS

INTERNATIONAL ELECTRONIC JOURNAL OF MATHEMATICS EDUCATION
e-ISSN: 1306-3030. 2017, VOL. 12, NO. 3, 735-747

The Effects of 'Geometry Sketchpad' on Grade 12 Learners' Performance in Geometry

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ABSTRACT

Learners at Grade 12 level persistently show a weak conceptual understanding of geometric concepts (DNEA, 2011, 2012, 2014). The study was guided by Bruner's (1960) Constructivist Theory, using Understanding by Design teaching approach to explain Geometrical concepts. The study was qualitative, using non-equivalent pre-test and post-test quasi-experimental design. Cluster random sampling was used to select a sample of 176 Grade 12 learners from two purposively selected secondary schools. The findings revealed that at 95% confidence level ρ=0.004; Mann-Whitney U test = 2 914.500, there was a statistically significant difference between the two groups in terms of learner performance on Geometry topics. The study recommends Mathematics teachers to use ICT-driven pedagogy when teaching Geometry in order to improve learners' academic achievement.

KEYWORDS
ICT-driven pedagogy, Geometry, performance, Geometer's Sketchpad (GSP), Understanding by Design (UbD)

ARTICLE HISTORY
Received 15 September 2017
Revised 10 November 2017
Accepted 22 February 2017

Introduction

Mathematical skills and knowledge are essential for the attainment of the Sustainable Development Goals (SDGs) – Goal 4 (United Nations (UN), 2015), Vision 2030 and development of a dynamic knowledge-based economy society (Government of the Republic of Namibia, 2004). In fact, Mathematics is seen by many people as an essential and core subject for scientific, technological and economic development (Umameh, 2011; Mbugua, Kibet, Muthasa, & Nkonke, 2012). In spite of the important role that Mathematics plays in many fields of

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work, there is evidence that learners continue to perform poorly at national examination level in some countries globally (Ali, 2013; Karue, & Amukowa, 2013). In Namibia, the national average pass rate in Grade 12 Mathematics at the Senior Secondary Certificate (NSSC) Ordinary level is 38.6% over a period of seven years (2008-2014) (Directorate of National Examinations and Assessment ((DNEA), 2008, 2009, 2010, 2011, 2012, 2013, 2014). Further, the National Examinations Statistics shows that an average of more than half (55.7%) obtained no-passing symbols; of which, 50.8% of the learners achieved between E-G and 4.9% were ungraded (U) (EMIS, 2014). Furthermore, EMIS (2014) documented that on average only about 44.3% of the learners scored passing symbols (A* - D) in Mathematics for the past seven years. The Examiners' reports on NSSC Ordinary Level Mathematics stated that teachers should concentrate on teaching topics that proved to be difficult to learners, such as Geometry (DNEA, 2011, 2012, 2013, 2014) as questions in this category were the worst answered. However, Mateya (2008) confirmed that some Namibian learners at Grade 12 level had a weak conceptual understanding of geometric concepts, not knowing their properties and hardly able to make basic informal deductions. Therefore, the focus of this study was on three of the five Geometry topics in the Mathematics NSSCO curriculum, namely, geometrical terms and relationships, symmetry and angle properties.

Information and Communication Technology (ICT) has been used to deliver instruction in some countries around the world (Myers, 2009; Idris, 2009). In line with the current development in instructional design, Namibia too has introduced the use of ICT in schools to enhance learning. However, a few schools thoroughly applied ICTs in classroom practices (Simasiku & Simataa, 2012; Ngololo, Howie & Plomp 2012), let alone to enhance teaching of mathematics. This study used UbD from Wiggins and McTighe (2005) to plan the learning experience, conduct the lesson and obtain acceptable evidence of learners competence in the identified topics; and the Geometer's Sketchpad (GSP) as remedial teaching tool to improve learners' performance in Geometry (Myers, 2009; Idris, 2009).

Literature Review

This study was informed by Bruner's (1960) Constructivist Theory which emphasises that content should be structured in considerable detail to allow learners to easily grasp the information, active and should be based on their prior knowledge. The Constructivist-based learning environments should have problem-solving activities, provision of stimulating learning environments, cooperative learning and the promotion of learning through exploration (Roblyer, Edwards, & Havriluk, 2010). The UbD framework was further adopted to realise the active, exploratory, stimulating learning process.

The UbD framework was developed by Wiggins and McTighe (1998) as a planning framework to guide curriculum, assessment and instruction. Under this framework, learning outcomes and assessment were gathered before specifying instructional procedures in order to enhance learners' understanding during lesson presentation (Anwaruddin, 2013). McTighe and Wiggins (2012) stated that UbD calls for collaborative learning, use of technology and other teaching approaches in order to design, share, and critique learning content. Further, the planning framework emphasises the use of a backward design process (Social Studies Center for Educator Development (SSCED), 1999) as a road map to instruction and assessment design which was adopted as a guide for lesson planning. This study used the UbD lesson plan format in preparation of the lessons and assessment to test the Experimental Group's understanding of Geometrical concepts.

Figure 1 shows the UbD Backward design process.

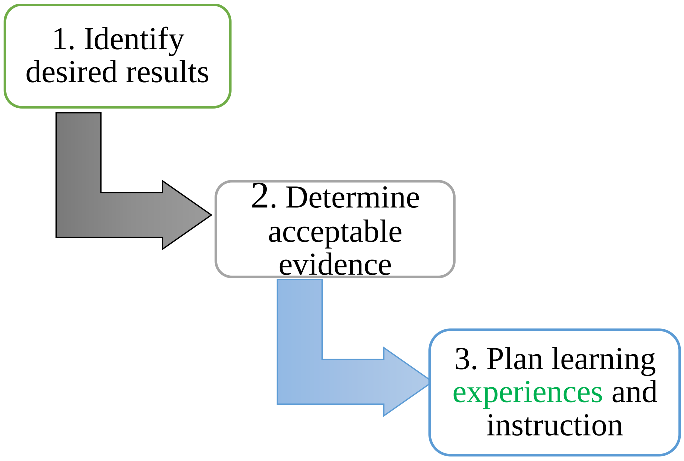

Figure 1. Stages of the UbD "Backward" Design process (Wiggins and McTighe, 2003)

Learners' understanding was assessed using UbD facets of understanding. Facets of understanding were used as indicators of understanding Geometry topics. The following concepts: Explain, Apply and Perspective were used in lesson planning, designing pre-test and post-test questions to promote deep and critical thinking in learners.

Wenglinsky (1998) used UbD teaching approach and National Assessment of Educational Progress (NAEP) achievement data to investigate the relationship between the various uses of technology and achievement in Mathematics of U.S Grade 8 learners. Wenglinsky found a significant relationship between the NAEP test scores and the use of technology that focused on mathematical projects, problems and simulations that promoted application of knowledge and higher order thinking. He also found that when computers were used for higher-order thinking skills, learners performed better and so suggested that teachers focus on using computers to apply higher order skills learned elsewhere in class. In the same vein, Ogdol and Lapinid (2013) used UbD lesson plan in order to develop learners' mathematical understanding on linear equations in two variables. Ogdol and Lapinid found UbD unit plan or the backward curriculum to have led to the development of above 70% learners' mathematical understanding. Although, Ogdol and Lapinid's (2013) study did not incorporate technology, their study findings assisted in explaining the effectiveness of the UbD approach. Mateya (2008) recommended that the teaching and learning of Geometry should involve more hands-on activities that would enhance learners' conceptual understanding of geometric concepts.

Furthermore, correct spelling and pronunciation of geometrical terms should be used at all times.

Idris (2009) conducted a study on the impact of using Geometers' Sketchpad (GSP) on Malaysian learners' achievement and Van Hiele Geometric thinking. Initially, Idris found no statistically significant difference between the pre-test Geometry performances of the Control and Experimental group. After the intervention, however, Idris (2009) found a statistically significant difference (α = 0.05, = 0.788,¯ = 19.65 and p = 0.02) between post-test Geometry performances of learners who had been taught using GSP and those who were not. Further, in the post-test, the Control group exhibited a mean of 13.08 whilst the Experimental group had a mean of 19.65. A similar study was conducted by Myers (2009) using GSP and Florida Comprehensive Assessment Test (FCAT) to investigate the effect of technology on Grade 10 learners' achievement in Geometry, interaction with gender and socio-economic status and their Van Hiele levels. Myers' (2009) study found a significant difference between the Control and Experimental groups at α = .05 level of significance, ρ = .001. Both Idris (2009) and Myers (2009) recommended the use of Geometers' Sketchpad as an effective tool in teaching and learning Geometry at secondary school level as it yielded improved results. Although, Van Hiele Theory was not used directly in this study, the findings obtained in the study described in this section helped in the understanding of the achievement levels of Grade 12 learners. Besides, the significant level of α = 0.05, which indicates an improvement in performance using GSP, was used as a benchmark for the present study.

The UbD teaching approach was drawn from learning theories that focus on transformational learning, supports authentic tasks and calls for teaching for understanding, with emphasis on problem-based learning and the use of pictorial and symbolic activities (Clayton, 2011). Therefore, if teachers are applying UbD teaching approach which is based on Bruner's Constructivist Theory ideas, learners might perform better in school subjects.

Methodology

The study adopted a sequential explanatory research design, a mixed research design approach; using non-equivalent pre-test and post-test quasi-experimental design and a survey. In a non-equivalent pretest-posttest Control group design, intact classrooms were used (Gay, Mills & Airasian, 2009) since the classes were already grouped and were used as they are in the respective existing schools. In order to determine whether a significant difference existed between the scores of the Control and Experimental group, the following hypothesis was tested:

$\boldsymbol{H_0}$: *There is no significant difference between the performance of learners who were taught Geometry using UbD and those taught using traditional methods.*

$(H_0 : \mu_{Control} = \mu_{Experimental})$.

$\boldsymbol{H_1}$: *There is a significant difference between the performance of learners who were taught Geometry using UbD and those taught using traditional methods.*

$(H_1 : \mu_{Control} \neq \mu_{Experimental})$.

Two schools were purposefully selected on the basis that one had GSP software while the other school did not. Cluster random sampling was used to select the sample of participating classes. At each school, two Grade 12 Mathematics NSSC Ordinary level classes were randomly selected to form a cluster. Since School A had GSP software it served as an Experimental group. A cluster at School A consisted of two classes, referred to as Group E (Experimental), each class had 44 learners, totalling 88 learners. Meanwhile, School B was a Control group and had no GSP software. School B had four classes, each class had 44 learners. A cluster at School B consisted of two, referred to as Group C (Control), each class had 44 learners, totalling 88 learners. In total, participating learners from both schools (A and B) were 176.

Pre-test and post-test questions were set up by adapting Mathematics NSSC Ordinary level past question papers on geometrical terms, relationships, angle properties and symmetry. The pre-test and post-test were aimed at testing learners' knowledge and understanding on Geometry topics before and after the intervention respectively. The total marks of each test were twenty-five (25). The questions were categorised based on Geometry topics (geometrical terms, relationships, angle properties and symmetry). The Control and Experimental groups were taught separately the same topics of Geometry which were: geometrical terms and relationships, angle properties and symmetry (NIED, 2010).

Data collection procedures involved, randomly selecting two participating classes from the Grade 12 classes first. The Mathematics pre-test was then administered to the two groups the day before the commencement of teaching and the results of the individual learners were recorded for analysis. Teaching was carried out for two weeks on school days during the afternoon, from 14:00 – 15:00 to avoid disruptions of normal teaching schedule of schools. The post-test was conducted immediately after completion of the two weeks of teaching. The Experimental group at School A was taught using Understanding by Design (UbD) teaching approach. The introduction to each topic was sequenced in the following order based on the UbD backward design:

Stage 1: Objectives that learners should know by the end of the unit, in measurable terms, were clearly specified in a question format so as to deepen learning and help them achieve the desired understanding. The following facets of understanding were used: explanation, interpretation, application, perspective, empathy and self-knowledge.

Stage 2: The forms of assessment i.e. post-test and class exercises; that were used to determine that the learners had acquired the knowledge, understanding, and skill to answer questions were stated. The activities involved such as investigating geometric objects, proofs and properties to deepen learners' understanding of geometric concepts.

Stage 3: Geometrical objects, proofs, and angle properties were explained using GSP software for 25 minutes. The teacher summed-up by stating the desired understanding required from the presentation.

The learners in the Control group at School B were taught using traditional modes of teaching such as explanations, demonstrations on the chalkboard, discussions with teacher and using a textbook. All the five lessons ran for 40 minutes.

The data was analysed using the Statistical Package for Social Sciences (SPSS) software. The normality of the test scores was assessed using Shapiro-Wilk test. Intra-group comparisons were made in each group using Paired sample t-test in order to compare the Mathematics pre-test results to the post-test results. Further, Levene's t-test was carried out at a significance level $\propto = .05$ in order to determine if the two groups i.e. the Control and Experimental group have about the same or different amounts of variability (Cohen, Manion, & Morrison, 2011). Thereafter, a Mann-Whitney U (non-parametric) test was used to test for significance between the Control and Experimental post-test scores since the variance between the two groups was assumed to be unequal (Cohen et al., 2011).

Results

The normality of the test scores was assessed using the Shapiro-Wilk test, because it has the ability to handle large sample size and is the most powerful normality test (Keskin, 2006) at significance level $\propto = 0.05$ (Cohen et al., 2011).

Table 1. Tests of Normality of pre-tests and post-test scores

Data	Group	Total N	Test Statistics	Asymptotic sig (2-sided test)
Pre-test scores	Control	88	0.979	0.159
	Experimental	88	0.979	0.002
Post-test scores	Control	88	0.988	0.576
	Experimental	88	0.968	0.027

The ρ −values of the Shapiro – Wilk test (ρ = 0.002; 0.027) for the Experimental group's pre-test and post-test scores were less than 0.05; this meant that the test scores of the Experimental group deviated from a normal distribution. However, in both cases of the pre-test and post-test scores of the Control group was normally distributed because the ρ-values of the Shapiro - Wilk test (ρ = 0.159;0.576) were greater than 0.05 ($\rho > 0.05$). Parametric tests were carried out for both groups to test for significance since each group sample had more than 15 learners (Kothari & Warner, 2007).

All parametric and non-parametric tests were conducted at 95% confidence level. Descriptive statistics was carried out first, as shown in Table 2, 3, 4 and 5.

Table 2. Mean, Standard deviation and other statistics of the pre-test for the Experimental group

	Group	Descriptive	Statistics
Pre-test scores	Experimental	Mean	13.78

of learners		95% Confidence Interval for Mean	Lower Bound	13.08
			Upper Bound	14.48
		Variance		10.930
		Std. Deviation		3.306
		Minimum		3
		Maximum		19
		Range		16
		Skewness		-0.776

The mean interval of the pre-test scores for the Experimental group lies between 13.08 and 14.48. The pre-test minimum score of the Experimental group was 3, the highest learner scored 19 and the difference (range) between the highest score and lowest score was 16. The pre-test scores for the Experimental group were negatively skewed (-0.776).

Table 3. Mean, Standard deviation and other statistics of the pre-test for the Control group

	Group	Descriptive		Statistics
Pre-test scores of participant	**Control**	Mean		13.73
		95% Confidence Interval for Mean	Lower Bound	13.10
			Upper Bound	14.35
		Variance		8.683
		Std. Deviation		2.947
		Minimum		7
		Maximum		22
		Range		15
		Skewness		0.147

Meanwhile, the Control group's average performance lies between 13.10 and 14.35. The highest score was 22 and the minimum score was 7. The difference (range) between the highest score and lowest was 15. Unlike the pre-test scores of the Experimental pre-test, scores of the Control group were positively skewed (0.147). In addition, the pre-test results showed that the standard deviation of the Experimental group of 3.306 was higher than the Control group (2.947). Further, the results also indicate that there was more variability among the Experimental group (10.930) than among the Control group (8.683). This is because the scores of the Experimental group were unevenly distributed.

The tables (Table 4 and Table 5) show the descriptive statistics after the intervention.

Table 4. Mean, Standard deviation and other statistics of the post-test for the Experimental group

	Group	*Descriptive*		*Statistics*
Post-test score of learners	**Experimental**	Mean		15.32
		95% Confidence Interval for Mean	Lower Bound	14.74
			Upper Bound	15.90
		Variance		7.507
		Std. Deviation		2.740
		Minimum		10
		Maximum		21
		Range		11
		Skewness		-0.105

After the intervention, the mean interval at 95% confidence level of the post-test scores for the Experimental group lies between 14.74 and 15.90. The minimum score on the post-test of the Experimental group was 10 and the highest score was 21. Additionally, the post-test scores for the Experimental group were negatively skewed, which implies that most learners in the Experimental group had scored high marks on the post-test and only a few scored low marks.

Table 5. Mean, Standard deviation and other statistics of the post-test for the Control group

	Group	*Descriptive*		*Statistics*
Post-test score of learners	**Control**	Mean		13.81
		95% Confidence Interval for Mean	Lower Bound	13.02
			Upper Bound	14.59
		Variance		13.836

Std. Deviation	3.720
Minimum	4
Maximum	23
Range	19
Skewness	-0.124

The mean of the Control group lies between 13.02 and 14.59. The minimum score on the post-test of the Control group was 4 and highest score was 23. Similar to the post-test scores of the Experimental group, the Control group post-test scores were negatively skewed.

A paired t-test was carried out to compare the pre-test and post-test scores of the Experimental group and for the Control group. Table 6 presents the paired samples t-test results of the Experimental group.

Table 6. Intra-group comparisons (Paired Samples t-test): Experimental and Control Group

Group		T	Df	Sig. (2-tailed)
Experimental	Pre-test scores of learners - Post-test score of learners	-3.837	87	0.000
Control	Pre-test scores of learners – Post-test score of learners	-0.184	87	0.854

Table 6 shows that at α = 0.05 and df = 87, the value of $t = -3.837$ and the $\rho - value = 0.00$. These results indicate that the mean score of the Experimental group on the Mathematics pre-test and post-test were statistically significantly different. Further, at 95% confidence interval ($\propto = 0.05$) and $df = 87$, the value of $t = -0.184$ and ρ −value was = 0.854. The $\rho - value > \propto$ (0.05), this shows that there was no statistical significant difference between the Control groups' pre-test scores and post-test scores.

The Experimental group and Control group pre-test scores were compared in order to determine if the two groups of learners were comparable in ability before the intervention. Levene's t-test was used to determine if they had about the same or different amounts of variability between scores (Cohen et al., 2011). Table 7 presents Levene's t-test and t-test for Equality of Means calculations carried on the pre-test scores:

Table 7. Independent Samples Test of the pre-test for the Control and Experimental group

Type of test	**Levene's Test for Equality of Variances**	**t-test for Equality of Means**

		Sig.	T	Df	Sig. (2-tailed)
Pre-test scores of learners	Equal variances assumed	.620	.120	174	.904
	Equal variances not assumed		.120	171.747	.904

Table 7 shows that the t-test for the pre-test on Geometry topics with the degree of freedom, $df = 174$, ρ-value = 0.620 for Levene's test is greater than $\propto = 0.05$, which indicates that equal variances is assumed. The ρ (sig. (2 tailed)) = $0.904 > 0.05$; thus at 95% confidence level implies that there was no significant difference in the mean performance of the Experimental pre-test and Control group pre-test. Thus, the Control group and Experimental group could be said to have been equivalent at the beginning of the intervention. Therefore, the two groups of learners were comparable in ability. Consequently, the degree of change occurring in the post-test results of the treatment group would be attributed to the treatment (Gay et al., 2009; Cohen et al., 2011).

Table 8 presents the Levene's t-test and t-test for Equality of Means calculation for the post-test scores.

Table 8. Independent Samples Test of the post-test for the Control and Experimental group

Type of test		**Levene's Test for Equality of Variances**	**t-test for Equality of Means**		
		Sig.	T	Df	Sig. (2-tailed)
Post-test score of learners	Equal variances assumed	.027	3.069	174	.002
	Equal variances not assumed		3.069	159.936	.003

The t-test for the post-test on Geometry topics with the degree of freedom, $df = 174$, ρ-value = 0.027 for Levene's test is less than $\propto = 0.05$. This indicates that the variances are unequal in both groups. Since equal variance was not assumed, a Mann-Whitney U (non-parametric) test was used to test for significance. Table 9 shows the statistics.

Table 9. Independent-Samples Mann-Whitney U test of the post-test for the Experimental group

Total N	*Test Statistic*	*Asymptotic sig.(2-sided test)*
176	2 914.500	0.004

Now, since the ρ -value $= 0.004 < 0.05$, the null hypothesis was rejected. Therefore, at 95% confidence level there was a significant difference in the Geometry topics post-test performance of the Experimental and Control group.

Discussion

The significant difference in performance between the Experimental group and the Control group is attributed to the use of ICT-driven pedagogy, advocated for in Bruner's (1960) Constructivism Theory, particularly in the three stages of intellectual development. Bruner (1960) argues that concrete, pictorial and symbolic instruction, leads to more effective learning and good performances in subjects.

It is apparent from the findings, that adaptation of the UbD teaching approach with GSP can boost understanding of Geometrical concepts by learners. The use of the tool and the teaching approach has enhanced the explanation of Geometrical shapes and concepts that are difficult for learners to visualise in their minds. The tools also serve in promoting higher-order thinking skills, i.e., deeper understanding through the use of visuals and geometrical proofs. The use of pictures and symbols can enhance better understanding of the Geometrical terms such as symmetry and angle properties; and consequently enhance learners' performance. The findings of this study confirm that the use of GSP as a teaching tool lead to better performance of learners in Geometry (Idris, 2009; Myers, 2009). In addition, the use of UbD lesson plans proved to be a more efficient teaching method to enhance understanding of Geometrical concepts (Ogdol & Lapinid, 2013; Wenglinsky, 1998). Although Wenglinsky (1998) study did not use GSP nor focused on Geometry, the fact that his study used computers and UbD as a teaching approach in order to enhance learners' performance in Mathematics, it was still found to be comparatively relevant. The fact that the UbD teaching approach could be coupled with ICTs, shows that this approach is easy to adopt, practically acceptable for learners to use, keep them actively engaged and focused to realise the study objective of increasing performance in Geometry.

Conclusion

The results of this study revealed that using GSP coupled with the UbD teaching approach to teach Geometrical terms, relationships, angle properties and symmetry can have a positive effect on Grade 12 learners performance in Geometry.

Recommendations

- Based on the findings of this study, the researchers made the following recommendations. Mathematics teachers should be encouraged to use UbD teaching approach to teach Geometry topics i.e. geometrical terms, relationships, angle properties and symmetry, in order to improve the academic achievement of their learners.
- Teachers should be encouraged to use visual media (GSP) in teaching Geometry to strengthen understanding by simplifying abstract concepts.
- Schools that are equipped with ICT facilities should be encouraged to secure GSP software in order to enhance teaching and understanding of geometrical terms, relationships, angle properties and symmetry.

Disclosure statement

No potential conflict of interest was reported by the authors.

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