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Progressive Mathematics Initiative (PMI): An Innovative Approach to Teaching and Learning Mathematics, Evidence from Three Senior High Schools in Ghana

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Abstract:- In this paper students from three second cycle schools in the Bolgatanga Municipality were randomly assigned to treatment(n=40) and control(n=36) groups with the objective to compare two lesson delivery modes (Progressive Mathematics Initiative (PMI) and traditional teacher-centred teaching) on the effect on achievements in Mathematics with the use of SMART technology to design and delivery instructions for senior high schools and make a convincing case for the training of teachers in the PMI and its adoption in the SHS system in Ghana. The study relied on student's examination score from first term as baseline data with the experimental data to compare the two teaching methods. The Student t statistic and Cohen d were used to compare means and measure treatment effect size respectively.

The PMI approach shows remarkable improvement in students' achievement in the subject and can be described as promising since the one week of the experiment was quite short and will require considerable length of time to reach a definitive conclusion from its findings. Students and teachers alike were enthusiastic about the engaging and interactive nature in which lessons are created and delivered with the SMART technology and its assessment facilities. Science teachers as well as other subject area teachers can benefit from the planning and delivery of lessons from the use of the SMART technology.

***Keywords**:- Progressive Mathematics Initiative (PMI), Planning, Assessment, SMARTBOARD Technology, Achievement, Response Device, Clicker, Control Group (CG), Intervention Group (IG).*

I. INTRODUCTION

The goal of education is to prepare students for the world of work and make them effective citizens who can contribute intellectually to social discourse. It is very important and crucial that the student after completing the period of learning become economically productive. The current system of education is not doing and seem to be the complaint worldly. Education system is seriously behind the rapid technological changes taking place in the world of work and therefore something radical needs to happen in our current school system to bring knowledge and skills needed for work to the level of technological development.

The future will require young people to depend heavily on the skills and knowledge they develop from learning Mathematics to make critical analysis of challenging problems, imagine, and generate novel solutions and bring new ideas that are productive enough to ensure economic growth and at the same time give them the edge to compete in the global economy (Commission on Mathematics and Science Education, 2009).

Knowledge and skills such as creativity, critical thinking, collaboration, digital literacy, and communication are required for the 21st century industries are changing dramatically due to the fast and rapid changes in technology (Mancaballi & Richardson, 2016). Mancaballi and Richardson suggested further that, four additional skills of change mindset, computing, continual learning, and connections to the 21st century skills are needed for work. Consequently, the ability to provide the right human resource for the changing job market will be the biggest challenges of our educational system today. There is also the talk of industry 4.0; which will be driven by robotics and artificial intelligence, which threatens the jobs of millions of people in the immediate future (The Future of Jobs, 2016). What is obvious is that, the current education system cannot and will not be able to provide the kinds of skills necessary for jobs in this century and centuries to come. Business leaders, educators and parents alike agree that the current school system will not provide critical skills and competencies for the future world of work or to even become effective citizens in a complex global environment driven by the changing technologies.

Thus, the best sure way to get our citizens in the education system to reach levels of skills and competencies we envision for the future is to change the way we teach and learn Science.

The teaching and learning of Mathematics need to change from the teacher-centered methodology to one that is centered on the student. There is the need to help students develop the ability to conceptualize and construct knowledge from their everyday experiences. This can be achieved if the method of teaching and learning shifts from the traditional instruction delivery where the teacher spoon-feeds the students with knowledge rather than help them to construct and discover knowledge. As Pearson indicates, a teacher is supposed to impart the knowledge of method to the student but not the knowledge of facts since the later can easily be forgotten (Pearson, 1900).

The teaching and learning of Mathematics should focus on helping students to have appreciation of the processes or methods involve in Mathematics Teaching and learning. This can be achieved if the teacher understands the process too well to be able to explain it in the simplest, concise, and precise manner for the learner to grasps.

Additionally, the workplace environment is becoming more virtual and needs people to work on projects as teams. The current sitting arrangement in schools does not allow students to work as teams or collaborate effectively. A new paradigm is required to reconfigure the sitting arrangement and allow students to sit by roundtables, which will make it easier for them to work as teams.

Students naturally will like to be able to talk to each other or consult a colleague for some further explanation of some concepts or ideas in class which have not being so clear. The colleague can provide explanation in terms of language that they both understand very well. Also, to fully understand an idea or concept or anything you need to teach it to others. The new way of helping students to learn has double reward for a student who takes the initiative to teach other colleagues and the colleagues can understand what they are learning from the perspective of their own colleague(s).

Humans construct knowledge from interaction with each other and this can be possible if there is a more effective way for students to get unhindered access to each other in the classroom. So, the way to go in the technologically enhanced workplace is to start training students to be able to interact freely in the classroom environment.

Teaching and learning using SMART technology and reconfiguration of classrooms allowing students to sit in circles will promote collaboration and interaction among them (Goodman, 2006). If this method is used in such environment, it will make the teacher a more effective facilitator rather than being the main character in the centre of the teaching and learning process.

The Progressive Mathematics Initiative (PMI), which have the constructivist paradigm of learning at its core have instructions designed for the Science which have components for both formative and summative of assessments. Students will use SMART response devices (clickers) to answer the formative assessment questions after the teacher delivers about 15 minutes of instructions on lessons. The formative assessment is ungraded and are supposed to help gauge the level of understand as the lesson progresses. Questions for the formative assessments are meant to challenge learners as they struggle together as a team to provide answers. Results of the real-time polling of students' responses can be shown either as pie or bar charts. Based on the results, the teacher may be able to know whether there is the need to reinforce the instructions and then poll again or move to the next lesson.

Achievements in Science subjects are important and can be considered as a priority for all stakeholders in education. However, students' performances in these subjects, over the years do not seem to be impressive as evident in results released by the West African Examination Council (West African Examination Council, 2014,2015). There was a media storm when the 2016 West African Senior Secondary School Examination Certificate (WASSEC) was released (West African Examination Council, 2014,2015) The poor performance of students were analyzed extensively by both experts and ordinary people alike with often political undertone but what was obvious was that performance in Mathematics (core and electives) were not the best. The Chief examiner's annual reports in Science have consistently over the years bemoan the inability of students to appreciate scientific concepts by using mathematical concepts to solve real world problems or students do poorly in scientific problems drawn from real world or everyday experiences. In short, students perform poorly or have poor understanding of some of the most important concepts in Mathematics.

Ghanaian students have been taking part in international comparative studies in Mathematics and Science but largely these have been at the basic school level (the Trends in International Mathematics and Science Study (TIMSS, 2003;2005). Ghanaian students who took part in the 2003 study and 2005 performed poorly in both Mathematics and Science at global level and even in Africa, it was not a desirable result. Though the 2005 study saw slight improvement over the 2003 results (TIMSS, 2003;2005), the most recent global survey also shows very poor performance by African countries.

The Organization for Economic Co-operation and Development (OECD) also conducts global assessment of Mathematics and Science known as the Programme for International Students Assessment (PISA).

In the most recent world ranking of Mathematics and Science achievements conducted, Ghana was last among seventy-six nations (OECD, 2015). In that study, Africa represented by South Africa and Ghana were the worst performers in these two subjects among students who are fifteen years old and took part in the global assessments. Southeast Asian countries had been very consistent in their performance in the global ranking and maintain the first four high performers (OECD, 2015).

Can Ghana remedy the situation so that by the next five years we will be among the first ten nations? There must be deliberate efforts and consistent investments in terms of funding for projects and programs that are directed toward improving the teaching and learning of the Mathematics to get us out of the situation we find ourselves.

Because of the problems stated above, this research was proposed to sensitize all stakeholders in education to adopt a modern methodology in teaching and learning which will be more student-centered to enhance knowledge acquisition, understanding of fundamental concepts in these subjects and how to apply them to solve practical problems.

The time is now to take a fresh and critical look at our commitments to improving learning achievements and put new energies into our education system. This can be achieved by making changes for the future toward promoting deeper learning and understanding of Mathematics. These efforts will lead us to increase our competitive edge in the global economy and guarantee our future prosperity (Commission on Mathematics and Science Education, 2009).

II. METHODOLOGY

The study sought to compare two lesson delivery methods, namely; the Progressive Mathematics Initiative (PMI) with SMART technology and circular sitting configuration. It also considered the traditional lesson delivery, where the teacher gives instructions and follows with exercises, assignment, and end lesson tests.

The study has experimental design as its main design approach since two teaching methods are going to be evaluated and compared on which one has a better outcome in terms of students' achievement in Integrated Science. To make the comparison clearer there were two study groups: treatment group which received the new teaching method and the control group-which used the standard method of teaching.

The participants were randomly assigned to the intervention and control groups with the school participant is attending taken into consideration and was controlled for in the analysis so as eliminate the effect of differences as a results of school difference. The overall scores from exercises, assignments, projects, and end of lesson tests were compared in the two groups.

The study was double blind, neither teacher nor the participant knew who was in what group or from which programme or purpose of study disclosed to them. In effect neither group knew each other while the experiment was carried out.

The progress of students in both intervention and control groups were measured using scores from assignments, exercises, and end of lessons test for the two groups of participants. The new approach had both formative assessments using response devices to poll participants' answers to assessment questions within the lessons after about 15 minutes of instructions and final summative assessments. The traditional mode assessed students in the usual way of exercises, assignment, and end of lesson test.

Three Schools comprising two Senior High Schools and a Technical and Vocational School in the Bolgatanga Municipality were involved in study. The schools were Bolgatanga Girls' Senior High School (BOGISS), Bolgatanga Senior High School (BIG BOSS) and Bolgatanga Technical Institute (BOTECH)

Students in their second year took part in the research since the new approach if found to be to effective in improving achievements can be used to teach them immediately as they progress into new levels and then take their final examination, which will then be used as a final evidence to support the study.

Sample and Sampling Technique

Second year students were divided into various programmes and classes and randomly selected programmes and classes according to the proportion from each school and from the selected programmes and classes participants were randomly chosen from by probability proportion to class size to take part in the study.

The sampled participants were then randomly assigned to the two groups; intervention group (IG) and control group (CG). Participants were not required to disclose their programmes to each other and who was in the interventions or control groups were also not disclosed to the participant and the teacher who gave the instructions during the experiments. The reasons for the grouping of students by programmes were that science and agriculture students tend to have some strength in both Mathematics and Science or had good grades in them from the Basic Certificate Examination (BECE) and therefore, dividing them will ensure similarities among students and programmes.

Sample Size

Often, experimental studies need to be reviewed by Institutional Review Board (IRB) or Ethic Committee or the grant provider to ensure that subjects are not exposed to harm since the study involves people or even if there is some level of harm not too large a people are expose to such harm. So, there will be the need as part of the study protocol to justify the number of participants that were involved in the research. If too large a sample is used, it may have cost implication and exposing many people to harm which may not in any way improve statistical significance of the study.

In general, the larger a sample size the better your statistical accuracy and precision of your estimates. However, when the sample is relatively small, it may have some problem with effect size and statistical power. Hence, the sample that is not too large or too small is required.

Effect Size and Power

In experimental study where the main objective is to establish whether there exists substantial difference between two means or proportions or any parameter of interest, sensitivity analysis is done to show at what sample size can we show that there is an effect. Power is just the probability that such an effect does exist (Ryan, 2013). If the power is established, then how much is the effect, and this leads us to the effect size.

There are specific statistical packages for determining the power, effect size and sample size but in this study, they were calculated using Stata 14.1. The researcher first chose a level of error that can be tolerated for this study and sample size for the experimental group and then computed the effect size, power and the sample size of the control group.

Both the power and effect size are probabilities and are significant level at 0.05, effect size and power are 1.00 and 0.99 respectively showing that if the experimental and control are 40 and 36 respectively, then effect of the treatment is substantial.

Sample Size Determination

Often, pilot survey or existing similar study variance may be used in the determination of the sample size of a plan research. This study rather relied on data collected from students from the same school using a topic elicitation questionnaire. It asked the students to list three topics in both Mathematics and Science in order of importance they will like to study and provide the examination scores in both subjects from their first term examination. The examination scores were used as a pretest and its analysis provided the variance which was used for the calculation of the sample size, power, and effect size for this study.

Though the required sample size for both groups was supposed to be 76, a total of 79 students were selected to allow for students who may be absent. In most surveys, allowance is always made for non-response if from previous study the non-response rate is known. So, the allowance made for 3 students can be considered as a non-response of some sort.

Data Collection Instruments

Scores from exercises, assignment, and test within and at end of lessons were the source of data for the research with questionnaire for study participants to evaluate their experiences in learning with the new method. The scores and questionnaire were integrated and used in the analysis of the study.

Also, the topic elicitation questionnaire was administered to students in the study, which asked for their examination score in Mathematics for the first term end of term examination. The scores were used to calculate the variance which helped in the determination of the statistical power, effect size and sample size for the two groups.

Student participants and teachers completed a set of questionnaires on the experiences, opinions, and attitudes on the new approach of teaching and learning Mathematics, and the teacher-centered approach or conventional way of teaching.

Data Analysis Procedure

Since the study was to compare the traditional delivery of instructions and new approach where the teacher gives a brief delivery of instructions and uses SMART technology. Students interacted freely with each other which allowed them to construct knowledge. The new roundtable sitting arrangement made it easy for the students to move about freely to interaction.

The topic elicitation form and evaluation questionnaire for both teachers and students were entered using data capturing template developed in Census and Survey Processing Package version 7.1 (CSPro 7.1) template. The entered data was then exported to Microsoft Excel for cleaning and final preparation for analysis.

Preliminary analysis explored the choice of appropriate final analysis examining charts that illuminate this choice. The t-statistic was used in the statistical analysis to test how significant the difference between the mean scores of both group and the lack of it.

The scores from the first term examination was analysed together with the study data since it can be possible that the mere environment and conditions of the study can lead to some gain in performance for both groups. This can make in difficult to see clearly the effect of the intervention in the experimental group. So, the first term data acted as a baseline since the traditional teaching method is used in teaching the students until they were examined at the end of the term.

III. RESULTS AND DISCUSSIONS

The baseline results show a slightly lower average score in Science for the control group (60.06) than the intervention group (60.45). After the experiment, the intervention group's average score rose to 90.46 and higher than the control group (70.54) though it also saw an increase.

The lowest score for Science was higher in the control group than the intervention group for baseline. In the case of the study group, Science had a higher lowest score in the intervention than the control as shown in Table 1.

The results from the Integrated Science is not very different from that of the Mathematics in terms of the general conclusion. The variance test shows equal variance in the baseline scores and unequal variance from the study results when the test is conducted at significant level of $\alpha=0.05$, this can be seen from Tables 2 and 3.

The comparison of the result of Science before the study indicates also the same performance for CG and IG as shown in Figure 1 and 2. However, after the study the IG performed far better than the CG. The lower quartile mark in the IG is the same as that of the upper quartile of the CG. It also indicates that the IG had a higher median score than the CG, but we may not be able to conclude that the difference between them is remarkable. A very definitive claim can be made about the performance of the two groups if a test statistic is performed.

A logical way to confirm what is going on is to perform student's test for both the baseline and study data. These are shown in the tables 4.4a and 4.4b, as presented in the next section;

Again, Table 4 shows that the mean or average score in Science performance of students appears not to have any important difference between the two groups but the difference is very much pronounced in the Table 5. This is confirmed by the fact that (Prob. $(T < t)=0.0000 < \alpha=0.05$) if we test at significant level of $< \alpha=0.05$. Average Science scores in the intervention group has remarkable improvement than control group, though the control had the mean score also increasing after the study. The Cohen's d is very high and far higher than the cut off value proposed by Hastie ($d = 0.40$) for educational research and even that of Cohen ($d = 0.7$)

Hattie proposes an average magnitude of effect size of d=0.4 for educational intervention to be important enough to merit attention. He also argued that if an intervention met effect size criterion, the cost of it should be considered in that light else there will be no point to implement an expensive program (Hattie, 2015; 2009).

Goodman (2006) study started the development of the PMI and PSI program that help to bridge the huge gaps in Mathematics and Science and prepare high school students to take STEM courses in college. He made a case against the old sequence (biology, physics and chemistry) of the science subjects but resequencing with physics first follow by chemistry and biology supported by mathematics. Goodman started with sixteen students when he was hired as director for pre-engineering program for vocational school in New Jersey. The program became interesting and more students opted to take part. Other schools also experimented the program which shown tremendous promise to improve mathematics and science achievements. The biggest challenge was that there were no enough mathematics and science teachers, so the program had funding to train teachers from other disciplines under the supervision of university to award credit or degrees (Goodman, 2006).

Knab (2013) using data provided by New Jersey Department of Education showed that 8th graders' standardized test results were improving steadily in four districts in the New Jersey. The measure of the mathematics achievement was done by the official unit that conduct the regular measures in the district. The PMI is continuously used on regular basis to provide feedback.

The Gambia in 2012 to 2015 implemented the PMI and PSI program for cohorts of students in 16 Senior High Schools (Hanover Research, 2016). At the end of implementation, Hanover Research (2016) evaluated the program and concluded that students in the program performed better than students in other schools who were not involved in it when they sat for West African Examination Council final examinations for Senior High Schools in Mathematics (core and elective) and Science (Biology, Chemistry and Physics).

Lesotho Ministry of Education and Training (MoET) and New Jersey Centre for Teaching and Learning (NJCTL) commenced the implementation of the PMI and PSI in January after the ministry visited the Gambia program to learn from the program success. Grade 8, 9 and 10 teachers had training in the PMI and PSI methodology. The teachers started using the method in February 2017 and the program will end in October 2019 (CTL, 2017).

Interactive White Board has been the most effective way to teach students Mathematics and Science, since these subjects require much cognitive resources and students easily get bored or confused if the lessons are not engaging and interesting (Murcia & Sheffield, 2010). Also, the human brain has a naturally structure, which makes it to constantly seek what is novel and get bored from uninteresting, unchallenging, and repetitive task or activity. Effective use of the technology can cure the lack of novelty by introducing interesting and challenging activities for your learners. The technology makes it possible to connect to other resources that give further and precise explanations to mathematical and scientific concepts. When students are engaged, they learn better from peers or going to the internet to search for information that helps to explain further what they are learning. The finding from the analysis show, students' enthusiasm and passion in the use of the SMART Board technology helped in enhancing their understanding of the lessons taught to them.

IV. FINDINGS

Performance in Mathematics saw significant increase on the average and effect size of the difference is significant enough to require special attention to the PMI approach to teaching and learning. Relatedly, the difference in the mean performance in both Mathematics was very substantial for the experimental or intervention than control group.

Students were of the view that the SMART Board technology is an excellent resource for teaching in their classrooms.

V. CONCLUSIONS

The researcher in attempt to satisfy the objectives set for the study and the findings thereof, arrived at the following conclusions;

- The PSI approach to teaching and learning shown substantial improvement in Science achievement over the traditional teaching method used in our schools.
- Students and teachers prefer the use of the SMART Board technology in classrooms. The technology can provide rich, engaging, and interactive lessons which can capture the attention and interest of students. Science learning require critical and sustain attention and even getting involve in doing most of the learning tasks.

The study has strong promise for introduction of the PMI approach to teaching and learning of Science and therefore makes the following recommendations for policy actions by stakeholders of education. PMI approaches to teaching and learning Mathematics should to adopted in the Senior Schools since it has the potential to improve students' achievements.

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Table 1: Summary statistics for Mathematics and Science scores

	Baseline		Experimental	
	Mathematics		Mathematics	
Statistics	**CG**	**IG**	**CG**	**IG**
N	34	34	28	32
mean	59.39	55.80	67.75	79.30
median	60.95	53.00	73.00	80.83
Q_1	51.00	40.10	57.50	77.50
Q_3	74.10	72.00	81.50	86.67
sd	16.91	19.08	19.53	11.61
min	21.00	23.80	14.00	43.33
max	86.60	94.00	90.00	95.00

Table 2: Variance test for mathematics score (term 1)

Group	N	Mean	SE	SD	[95% Conf. Interval]	
CG	34	59.39	2.9003	16.9116	53.48454	65.28605
IG	34	55.80	3.2718	19.0777	49.14347	62.45653
combined	68	57.59	2.1808	17.9831	53.23981	61.94549
ratio = sd (CG) /sd (IG)					f = 0.7858	
Ha: ratio < 1	Ha: ratio! = 1		Ha: ratio > 1		Degrees of freedom =33,33	
Prob. (F < f) = 0.2463 2*Prob. (F< f) = 0.4925 Prob. (F > f) = 0.7537						

Table 3: Variance test for mathematics score

Group	N	Mean	SE	SD	[95% Conf. Interval]	
CG	34	59.39	2.9003	16.9116	53.4845	65.2861
IG	34	55.80	3.2718	19.0777	49.1435	62.4565
combined	68	57.59	2.1808	17.9831	53.2398	61.9455
diff		3.59	4.3722		-5.1465	12.3171
diff = mean (CG)-mean (IG)					t =0.82	
Ho: diff=0, Ha: diff<0 Ha: diff! = 0, Ha: diff>0 Satterthwaite's df=65.064						
Prob. (T < t) = 0.7924 Prob. (T > t) =0.4152 Prob. (T > t) =0.2076						

Table 4: student's test for mathematics score (term 1)

Group	N	Mean	SE	SD	[95% Conf. Interval]	
CG	28	67.75	3.6899	19.5252	60.1789	75.3211
IG	32	79.30	2.05230	11.6096	75.1106	83.4819
combined	60	73.91	2.1565	16.7040	69.5929	78.2231
ratio = sd (CG) /sd (IG)					f =2.8285	
Ha: ratio < 1	Ha: ratio! = 1		Ha: ratio > 1		Degrees of freedom = 27,31	
Prob. (F < f) = 0.9970 2*Prob. (F< f) = 0.0060 Prob. (F > f) = 0.0030						

Table 5: student's test for mathematics score

	SMART Board and attention in class		
Group	**Excellent**	**Very Good**	**Total**
Intervention	30	2	**32**
	93.75	6.25	**100.00**
	56.6	33.33	**54.24**
Control	23	4	**27**
	85.19	14.81	**100.00**
	43.4	66.67	**45.76**
Total	**53**	**6**	**59**
	89.83	**10.17**	**100.00**
Pearson chi2(1) =1.1759	**Prob.=0.278**		

Table 6: Rating of SMART Board use and attention in class

Group	N	Mean	SE	SD	[95% Conf. Interval]	
CG	28	67.75	3.6899	19.5252	60.1789	75.3211
IG	32	79.30	2.0523	11.6096	75.1106	83.4819
combined	60	73.91	2.1565	16.7040	69.5929	78.2231
diff		-11.55	4.2222		-20.0628	-3.0297
Cohen's d 0.73097 0.20375 1.2523						
diff = mean (CG)-mean (IG)					t = -2.7346	
Ho: diff=0, Ha: diff<0, Ha: diff! = 0 Ha: diff> 0 Satterthwaite's d. f=42.73						
Prob. (T < t) =0.0045 Prob. (T > t) =0.0091 Prob. (T > t) = 0.9955						

Table 7: Rating richness and interactivity of SMART Board lessons

Group	Rich and interactive lessons			Total
	Excellent	Very Good	Good	
Intervention	28	3	1	**32**
	87.5	9.38	3.13	**100.00**
	58.33	30.00	100.00	**54.24**
Control	20	7	0	**27**
	74.07	25.93	0.00	**100.00**
	41.67	70.00	0.00	**45.76**
Total	**48**	**10**	**1**	**59**
	81.36	**16.95**	**1.69**	**100.00**
Pearson chi2(2) =3.535 Prob.=0.171				

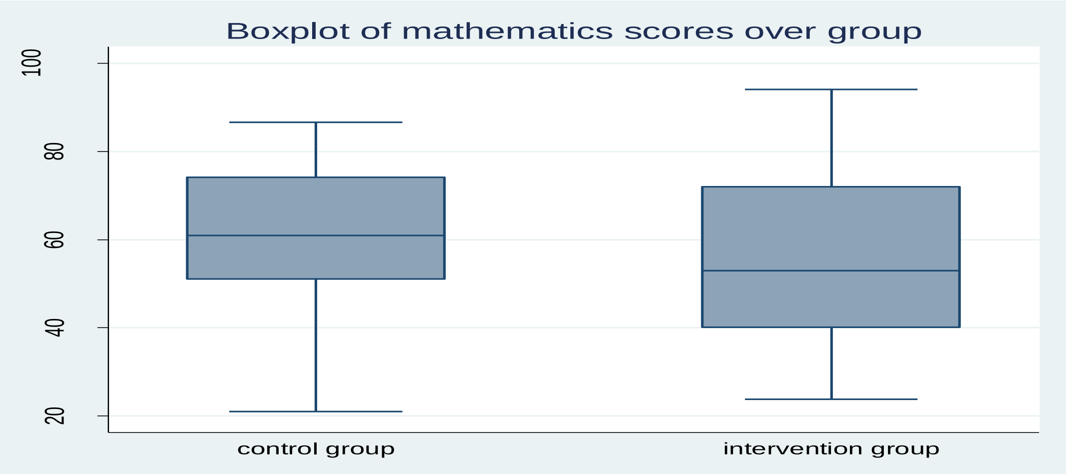

Figure 1: Mathematics scores from term one examination

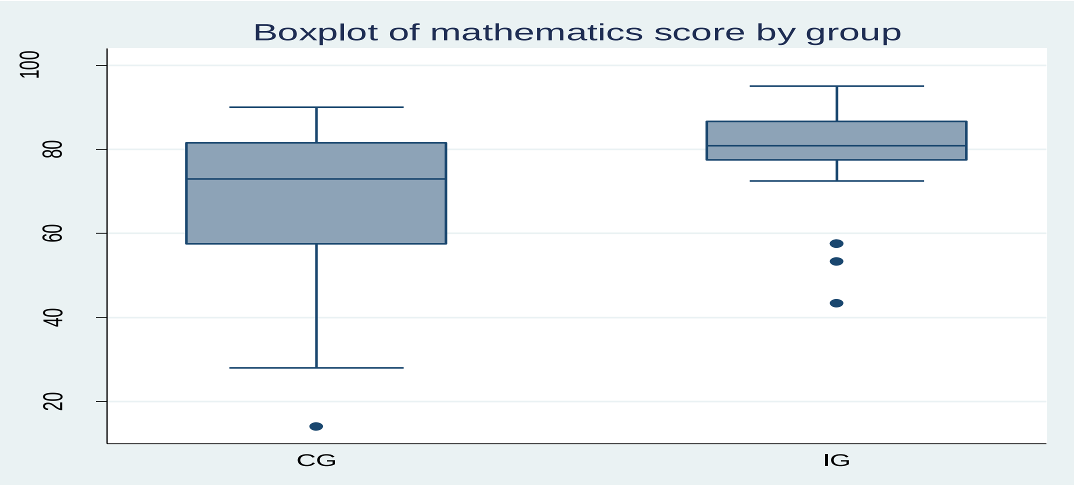

Figure 2: Mathematics scores from study