Using Differentiated Instruction to Foster Algebraic Thinking in Classrooms

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Article Info	Abstract
	This quasi experiment sought to use strategies of differentiated instruction (DI) to foster algebraic reasoning of Junior High School (JHS) year 2 students in the Winneba municipality, Ghana. The study employed Solomon four group sampling technique to collect pre-test and post-test data from 337 students. After the treatment, the independent t-test on the post-test gave the results ($M_1 = 11.2, SD_1 = 4.7$) and ($M_2 = 4.3, SD_2 = 3.1$) with $t(335) = 16.2, p(0.000) < 0.05$ indicating that, there was a significant difference between the achievement score of the experimental and control groups. The calculated effect size between the means of the experimental and control groups was approximately 0.7, an indication that the effect of DI strategies is large. It was recommended that, DI strategies should be employed in Ghanaian classroom to improve students' algebraic thinking.

Introduction

Variability in the mathematics classrooms is inevitable. Adebayo and Shumba (2014) stated that pupils come to classes in various permutations in terms of preferences, interests, background knowledge, language, communication, skills and readiness to learn. Quality teaching, according to Hafar (2015), is for one key purpose that is, to benefit below average, average and above average students. Consequently, mathematics educators are expected to synchronize students' variability and offer quality instruction that serves each student according to their special needs, learning styles and interests.

Differentiated Instruction (DI) is based on the belief that because there is variability among any group of learners, teachers should expect student diversity and adjust their instruction accordingly (Tomlinson, 1999). According to Holli (2008), DI is a set of strategies that help teachers meet each child where they are when they enter class and move them forward as far as possible on their educational path. Strategies such as flexible grouping, anchoring activities, compacting, tiered assignments, jigsaw, scaffolding, interest centers, alternative assessments etc. are used in a DI class.

Several researchers have used different strategies of DI in their attempt to improve their students' achievement. For example, Karadag and Yasar (2010), Bal (2016), Smith and Humpert (2012), Cannon (2017) and Hapasari, Darhim, and Dahlan (2018) employed different methodologies to assess DI in the mathematics classroom. These

DI strategies by Karadag and Yasar (2010), Bal (2016), Smith and Humpert (2013), Cannon (2017), Hapasari, Darhim, and Dahlan (2018) have mostly yielded positive results, some have reported improvement in the mathematics achievement of their students, while others reported improvement in students' attitudes positively. The results obtained by studies (Karadag & Yasar , 2010; Bal, 2016; Smith & Humpert, 2013; Cannon, 2017; Hapasari, Darhim, & Dahlan, 2018) that employed DI show that if the strategies of DI are applied effectively in the mathematics classroom, students' performance will improve and students' confidence will be built.

According to Bal (2016), DI was important for students' understanding, reinforce the subject better, makes mathematics lessons more entertaining, and improve students' ability to solve mathematical problems. A study by Smith and Humpert (2012) stated emphatically that, classes that implemented DI do not experience poorer performance on standardized achievement tests. The DI strategies adapted by Hapsari, Darhim, and Dahlan (2018) in the study were flexible grouping, tiered assignments and compacting. Findings from the studies indicated that, students who were initially reluctant to get involved with mathematical learning became involved voluntarily after given tasks that are appropriate to their individual capabilities and responded positively to flexible grouping.

In Ghana, DI was introduced in the 2012 JHS mathematics curriculum of Ghana, although the statement wasn't explicit. The 2012 curriculum stated that, teachers should cater for individual needs of every child to suit the variety of students in the mathematics classroom (Ministry of Education [MOE], 2012). However, in the 2020 common core mathematics curriculum, it was stated explicitly that, the curriculum is to be delivered through the use of creative approaches. Differentiation and Scaffolding are pedagogical approaches to be used within the context of the creative approaches (MOE, 2020). In the 2020 mathematics curriculum, teachers are encouraged to differentiate by task, differentiate by support and differentiate by outcome. The edge to insist on the use of differentiation in the Ghanaian mathematics classroom by curriculum developers presupposes that using differentiation will improve students' performance in mathematics hence this study.

The 2016 National Examination Assessment (NEA) report stated that, in Ghana, the percentage of private school pupils achieving the least minimum competency in mathematics was 82% for Grade 4 and 88% for Grade 6, with only 48% of the public-school pupils in Grade 4 and 67% of the public-school pupils for Grade 6 achieving at least minimum competency in mathematics. Additionally, proportion of pupils who were not able to answer at least 35% of the questions (i.e., achieve minimum competency) was high for public school pupils, with a third or more of the pupils falling below the minimum competency cut-off. In the Winneba municipality, Mills and Mereku (2016) found that about half of the JHS students (from public and private schools) are operating at minimum competency level of the National Minimum Standards in mathematics. The findings by the NEA, Mills and Mereku (2016) is an indication that the performance of students in mathematics leaves much to be desired especially in public schools in Ghana.

This study therefore, was an attempt to investigate how strategies of DI could foster students' algebraic reasoning in some selected public schools in the Winneba municipality, Ghana. The hypothesis that guided the study was:

H_o: There is no significant difference between the achievement scores of students exposed to DI and those not exposed to DI in the Winneba municipality.

Literature Review

Bal (2016) conducted a sequential mixed method study to find out the effects of DI teaching approach in sixth grade mathematics lessons in the algebraic learning field using a semi-structured interview and an Algebraic Success Test. Bal's (2016) study applied tiered teaching technique for experimental group. The experimental group had higher scores on both the last test and the persistency test as compared to the control group. The semi-structured interview revealed that DI was important for students' understanding, reinforcing the subject better, mathematics lessons were entertaining, and students were able to solve various examples with this teaching method. A study by Smith and Humpert (2012) sought to find out whether differentiated instruction affect students achievement. Smith and Humpert's (2012) study stated emphatically that, classes that implemented DI do not experience poorer performance on standardized achievement tests. However, unlike Bal (2016), Smith and Humpert (2012) could not confirm the positive results from differentiated instruction on students' achievement. Smith and Humpert (2012) attributed this result to the fact that, standardized tests were not directly related to the actual lessons taught using differentiated instruction strategies. Smith and Humpert (2012) suggested that, the best research design to test for the effect of differentiated is an experimental design with a control group.

A survey conducted by Hapsari, Darhim, and Dahlan (2018) regarding students' opinions on the types of instruction they require in mathematics classroom garnered these ten (10) characteristics: easy to understand, slowly/not rushing teaching, fun, not boring, not complicated, interspersed with humor, various question practices, not too serious, conducive class atmosphere for the instruction, and provided with rapid solution methods. These characteristics are a reflection of what most students want in the mathematics classroom. The DI strategies adapted by Hapsari, Darhim, and Dahlan (2018) in the study were flexible grouping, tiered assignments and compacting. Findings from the study by Hapsari, Darhim, and Dahlan (2018) indicated that, students who were initially reluctant to get involved with mathematical learning became involved voluntarily after given tasks that are appropriate to their individual capabilities and responded positively to flexible grouping. Responses from (Hapsari, Darhim, & Dahlan, 2018) students' questionnaire showed that 90% of students like learning groups, however, 70% of the students preferred that group members are appointed by their teacher. Even though Hapsari, Darhim, and Dahlan (2018) had positive responses on DI it is not clear if differentiated instruction affected the academic performance of students positively since the study did not gather data to assess students' achievement. Cannon (2017) evaluated the relationship between two third grades mathematics classrooms using an action research. The study adapted differentiated pedagogies (small group instruction, collaborative group instruction, and online instruction) for one class and the other class was taught using the traditional method. Findings from the pre-test and post-test showed that, the DI group (N=13) had a pretest mean score, $M = 56.92 \ (SD = 20.35)$ and post-test mean score, $M = 84.15 \ (SD = 12.20)$ while the traditional lecture style group (N=15) had a pre-test mean score, $M = 56.40 \ (SD = 19.30)$ and post-test mean score, $M = 82.00 \ (SD = 11.10)$. The *t-test* revealed there was no statistically significant difference in mathematics achievement between the experimental and control group. The results of the study could be attributed to the interaction between participants and class size. An action research by Karadag and Yasar (2010) sought to find out the effect of DI on students' attitude towards Turkish courses. Findings from the attitude scale, revealed that the post test results about the attitudes towards Turkish course were higher than the pre-test results and results from the $t-test$ indicated significant

difference in the attitude of students towards Turkish courses. The semi-structured interview conducted by Karadag and Yasar (2012) also indicated that differentiated approach influenced the students' attitudes toward Turkish course positively. The findings of Hapsari, Darhim and Dahlan (2018) agrees with Karadag and Yasar (2010) that differentiated instruction improves students' attitude positively. Most studies (e.g., Bal, 2016; Cannon, 2017; Hapsari, Darhim, & Dahlan , 2018; Karadag & Yasar, 2010; Orhan, 2023; Saparbaikyzy et al., 2023; Smith & Humpert, 2012; Yurt, 2022) conducted using DI are action research, survey, quasi experimental (one control and one experimental), therefore in this study, the researchers employed Solomon four group sampling technique as a strategy of enquiry.

Methodology

This study employed quantitative research method using quasi-experimental design. Mixed sampling method was used for the selection of schools and participants. According to Faryadi (2019), mixed sampling uses a mixture of random and non-random sampling principles. Random sampling was used to select four schools out of 16 JHSs in the Winneba municipality and purposive sampling was used to select two teachers. To guard against the threat of both internal and external validity, Solomon four group design was used to randomly select 4 intact classes in the four schools. The rigorous nature Solomon four group design assisted the researchers to detect whether a change in the dependent variables was due to the treatment in the study or the exposure of the pre-test. Ogunniyi (1992) defines Solomon four-Group design as the most rigorous quasi experimental design that can be used in quantitative studies.

In this study, schools A and B were categorized as experimental groups 1 and 2 respectively while schools C and D were categorized as control groups 1 and 2 respectively. In consultations with the head teachers and the mathematics teachers of the selected schools, JHS 2 students were purposely selected to participate in the study. The total number of student participants for the four selected schools were three hundred and forty-nine students (349), however three hundred and thirty nine (339) responded to the post-items, and the two teachers in the experimental groups also participated. Specifically, School A comprised of 54 students, School B was made up of 103 students, School C students were 82 students and, School D comprised 110 students. The study span over a period of twelve weeks. Figure 1 shows how the quasi experimental design was carried out and how each group was involved at every stage of the study.
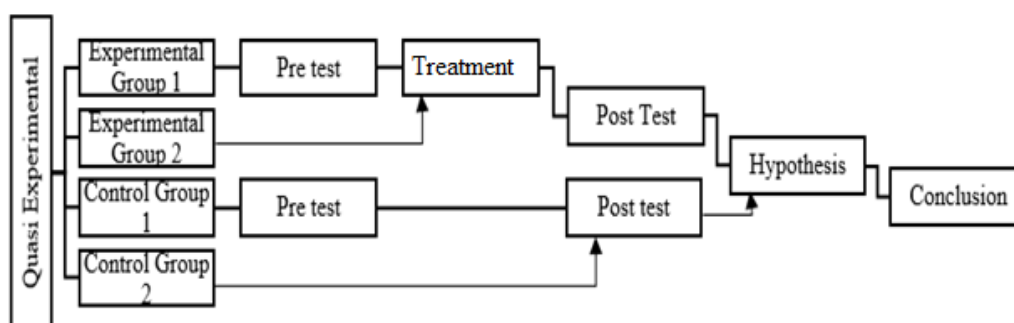

Figure 1. Design of the Study

From Figure 1, students in schools A (experimental group 1 [EG1]) and C (control group [CG1]) participated in a pre-test before treatment was administered to the experimental groups (EG1 and School B [EG2]). The administration of the pre-test was to ensure that the exposure of the pre-test had no influence on the results of post-test.

The treatment administered to EG1 and EG2 comprised of convenient strategies proposed by Owusu-Ansah and Apawu (2022): flexible grouping, tiered assignment, end-of unit assignments, algebraic thinking worksheets and ICT tools (though extremely challenging).

- *Algebraic thinking Worksheets*: Four worksheets were designed for students to practice questions on algebraic reasoning for review and correction by their teachers. Two worksheets were designed by the researchers for both experimental groups, and two other worksheets designed by the teacher of school A for his students, after he gained knowledge in differentiating by product. One week was given as the maximum timeline for the submission for each worksheet in this study.

- *End-of unit projects:* Because the study span for a term (12 weeks), end-of unit projects were used to evaluate topics treated during the term to ensure students keep up with topics being studied. The researchers assisted the teachers to design end-of unit projects. The researchers had to assist in the design of the end-of unit projects because teachers were hard pressed for time to complete their scheme of work and also conduct the specified number of exercises required.

- *Tiered Assignment*: Teachers practiced the use of tiered assignment in the teaching and learning activity. Teachers provided different trial questions to different groups of students in their lessons. Students were asked to answer the questions assigned to their group and after, share their solutions with the whole class. The presentation by students ensured that, they developed their interpersonal and linguistic intelligence (Gardner, 2006).

- *Flexible grouping:* In this study, flexible grouping was used by teachers in most of their mathematics lessons. In some of the lessons, students were asked to choose their own groups comprising of at most five students, other times the teacher grouped students and lastly students worked in pairs in some lessons.

- *ICT Integration*: The teacher in school A attempted to incorporate the use of a laptop, projector and speakers in the teaching and learning activity. The PowerPoint presentations and videos used in the lessons sustained students' attention and aroused students' interest throughout the lesson.

After the treatment, all the students participated in the post-test. Scores of two experimental groups were put together to represent total score for the experimental group and same was done for control groups. The mean scores of both groups were used to test the hypothesis.

Results

Before the analysis of the results, the assumptions for the use of Solomon four group as well as the assumptions for the independent sample $t-test$ were tested to ensure that the exposure of the pre-test did not have an effect on the post-test. Table 1 gives the results of the Levene's test used to check for equal variances of the pre-test.

Table 1. Test of Homogeneity of Variance

School	Mean	Levene Statistic	df1	df2	Sig.
A	12.9				
C	11.4	1.509	1	134	0.221

From Table1, the total pre-test scores for schools A (EG1) and C (CG1), $F(1,134) = 1.1509, p = 0.221$, was an indication that the variances are more or less equal. In addition to the Levene's test, a boxplot was drawn to illustrate the pre-test scores for the groups. Figure 2 shows a boxplot of the means of the pre-test score of schools EG1 and CG1.
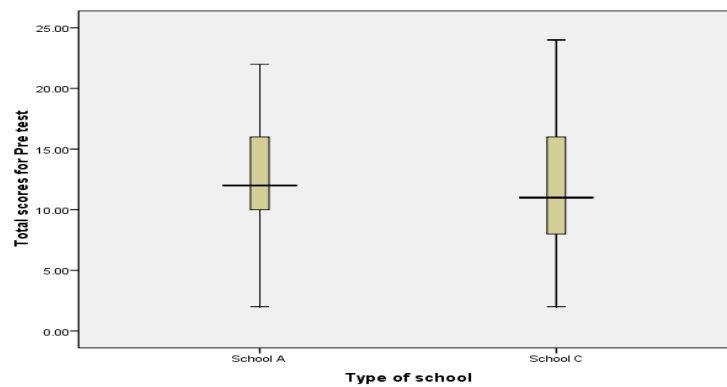

Figure 2. Boxplot of Pre-test Scores for EG1 and CG1

Also, Figure 2 is an indication that there was no difference between the pre-test scores of students in EG1 and CG1 since the box plots overlap. Therefore, it was concluded that as at the time of collecting the pre-test data, the performance of the students in the experimental and the control groups were similar. With this conclusion, the researchers proceeded with the treatment for the experimental groups.

Table 2 presents the results of the independent sample *t-test* between school B (EG2) and D (CG2). EG2 and CG2 not take part in the pre-test.

Table 2. Independent Samples $t - test$ for School B and D

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	95% Confidence Interval of the Difference	
									Lower	Upper
Post test	Equal variances assumed	19.44	0.00	14.88	211	0.00	7.46	0.50	6.48	8.45
	Equal variances not assumed			14.65	164.42	0.00	7.46	0.51	6.46	8.47

Results in Table 2 show that, there was a significant difference between the results (post-test) for school B ($M = 11.8, SD = 4.4$) and school D ($M = 4.4, SD = 2.7$); $t(211) = 14.879, p = 0.00 < 0.05$.

Table 3 presents the results of the independent *t-test* between school A (EG1) and C (CG1). EG1 and CG1 participated in the pre-test.

Table 3. Independent Samples Test for School A and C

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	95% Confidence Interval of the Difference Lower	Upper
Post test	Equal variances assumed	2.12	0.15	7.52	122	0.00	5.66	0.75	4.17	7.14
	Equal variances not assumed			7.13	85.74	0.00	5.66	0.79	4.08	7.23

The results in Table 3 also show that, there was a significant difference between the results (post-test) for school A ($M = 9.8, SD = 4.8$) and school C ($M = 4.1, SD = 3.6$), conditions; $t(122) = 7.518, p = 0.00 < 0.05$. Since the results for two independent $t - test$ in Table 2 and Table 3 show significant difference between the mean scores of the schools compared, it means that exposure of the pre-test had no effect on the results of the post-test. Similarly, an independent t-test was conducted between Schools A and B (EG1 and EG2) to also ascertain the influence of the pre-test on the post-test. Table 4 presents the group statistics for the two experimental (differentiated) groups that is, school A and school B. The results in Table 4 show that, the mean for school B (EG2) is greater than the mean for school A (EG1), although EG1 participated in the pre-test and EG2 did not.

Table 4. Group Descriptive Statistics of Post-test Scores

	Type of school	N	Mean	Std. Deviation
Total Scores for Post test	School A (EG1)	50	9.8	4.8
	School B (EG2)	103	11.9	4.4

Table 5 presents the results for independent samples t-test for school EG1 and EG2. The results in Table 5 show that there was a significant difference between the results for school A ($M = 9.8, SD = 4.8$) and school B ($M = 11.9, SD = 4.4$), conditions; $t(151) = -2.66, p = 0.009 < 0.05$. According to LavanyaKumari (2013), if there is a significant difference between the two experimental groups then the pre-test had some effect on the treatment and the experiment has been flawed. However, the mean scores of EG1 and EG2 Table 4 show that, EG2 which did not take part in the pre-test performed better than in the post-test that EG1 which took part in the pre-test. Consequently, it was concluded that the experiment had not been flawed and that the experiment was successful.

Table 5. Independent Samples Test for School A and B

| | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | 95% Confidence Interval of the Difference | |
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper
Post test	Equal variances assumed	0.03	0.85	-2.66	151	0.01	-2.10	0.79	-3.66	-.54
	Equal variances not assumed			-2.61	91.98	0.01	-2.10	0.80	-3.70	-.50

Finally, the researchers compared the post-test results of CG1 and post-test results of CG2 to further test whether the pre-test affected behavior independently of the treatment. Table 6 presents the group statistics for the post-test of CG1 and CG2. The results in Table 6 show that there was no significant difference between the results for school C ($M = 4.1, SD = 3.6$) and school D ($M = 4.4, SD = 2.7$), conditions; $t(182) = -0.625, p = 0.533 > 0.05$. Therefore, it was concluded that, exposure of the pre-test had no influence on the overall results.

Table 6. Independent Samples Test for CG1 and CG2

| | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | 95% Confidence Interval of the Difference | |
		F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper
Post test	Equal variances assumed	7.97	0.01	-0.63	182	0.53	-0.29	0.46	-1.20	.63
	Equal variances not assumed			-0.59	125.52	0.56	-0.29	0.49	-1.26	.68

The results from Table 2 to Table 6 indicate that exposure to the pre-test had no effect on the results of the post-test. Consequently, the post-test scores of EG1 and EG2 were combined to represent the score of the experimental group and the post-test scores of CG1 and CG2 were combined to represent the score of the control group.

Table 7 presents the results of the combined descriptive statistics for the experimental and control groups. Results from Table 7 show that, the experimental group had a mean score of 11.2, with a standard deviation of 4.7 and the control group had a lower mean score of 4.3 with a standard deviation of 3.1.

Table 7. Descriptive Statistics of Post-test

Group	N	Mean	Std. Deviation
Experimental	153	11.2	4.7
Control	184	4.3	3.1

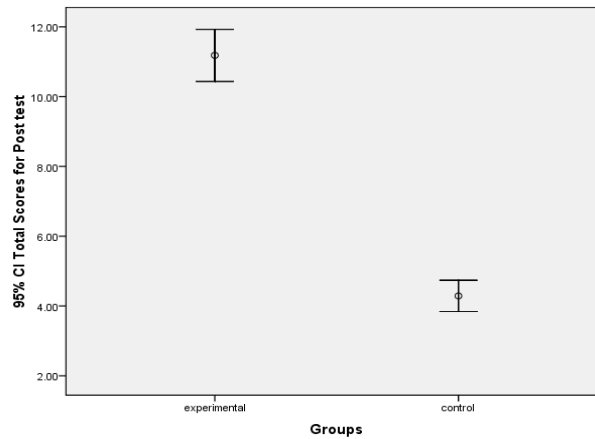Figure 3 shows the error bar graph of the means of the experimental and control group.

Figure 3. Error Bar Graph of Post-test Scores for Experimental and Control Group

From Figure 3, the error bar graphs for the experimental group and the control group do not overlap, this means that there is a difference in the performance of the experimental group and the control group, and it is likely that the treatment was successful. An independent sample *t-test* was conducted to ascertain whether the difference in the means of the experimental group and control group was significant. Table 8 presents the output of an independent sample *t-test* for the post-test.

Table 8. Independent Sample t-test for Control and Experimental Group

| | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | | 95% Confidence Interval of the Difference | |
	F	Sig.	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	Lower	Upper
Equal variances assumed	20.37	0.00	16.25	335	0.00	6.90	0.42	6.06	7.73
Equal variances not assumed			15.67	254.42	0.00	6.90	0.44	6.03	7.76

Results from Table 8 indicate that, there is a significant difference between the experimental groups and control groups at $t(254) = 15.7, p = 0.00 < 0.05$.

Calculated Effect Size

To find out whether the observed difference between the means of the experimental and the control groups was substantive, the effect size of the difference was calculated with $r \approx 0.7$. The result of the calculated effect size represents a large size effect, which means that the effect of the strategies of DI on the experimental was significant. The analysis results of the post-test, independent $t - test$ and the calculated effect size show that, significant difference exist between the performance of students exposed to some strategies of DI and those who were not exposed to DI.

Conclusions

The results of the post-test showed that mean scores of students in the experimental group were significantly greater than the mean scores of students in the control group after the treatment. These results could be attributed to the use of the DI strategies (algebraic thinking worksheets, end-of unit assignments, tiered assignment, flexible grouping, and ICT tools) employed in this study. The exposure of the experimental groups to the DI strategies improved the scores of students in the experimental group.

Bal (2016) used only tiered teaching as the DI strategy in a study and the experimental group obtained higher scores than students in the control group. The results achieved by Bal (2016) is similar to the findings of this study. This is an indication that, if DI strategies are rigorously and effectively implemented in mathematics classrooms, students are likely to achieve higher scores. Although this study showed a significant difference between the post-test scores of the experimental and control groups, the finding is in contrast with the findings of Cannon (2017) who found no statistically significant difference in mathematics achievement between the experimental and control group. Additionally, Smith and Humpert (2012) could not confirm the positive results from DI on students' achievement and attributed their result to the fact that, standardized tests were not directly related to the actual lessons being taught using DI strategies.

Based on the findings, it was concluded that statistically, students who were exposed to strategies of DI outperformed their counterparts who were not exposed to DI. Additionally, the strategies of DI have a large effect on students' algebraic thinking and DI is an effective strategy that helped improve the algebraic reasoning of students. It is recommended that mathematics teachers should employ strategies of DI that best suit their students in the teaching and learning activity.

Acknowledgements

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