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EFFECT OF USING SPREADSHEET IN TEACHING QUADRATIC FUNCTIONS ON THE PERFORMANCE OF SENIOR HIGH SCHOOL STUDENTS

Isaac Benning[1] and Douglas Darko Agyei[2]

[1]Aburaman Senior High School, Abura Dunkwa, Ghana.
[2]Department of Science and Mathematics Education, College of Education Studies, University of Cape Coast.

ABSTRACT: *The study employed a quasi-experiment design to evaluate the effect of using Spreadsheet Instructional Method as compared to a Conventional Method on students' performance in quadratic functions. Lessons delivered with both approaches employed a guided discovery; a mix of direct instruction and hands-on activities in a context in which mathematics learning have been deep-rooted in teacher-centred approaches of teaching. Interviews and teacher made achievement test were used to collect data from senior high school students in Ghana. Data was analysed using paired sample t-test and analysis of covariance for the achievement test whereas interviews were transcribed and coded using data reduction technique. The study showed that the Spreadsheet Instructional Method served a useful pedagogical approach, impacted more on the students' performance and has the potential of improving teaching and learning mathematics in Senior High schools. The use of the spreadsheet made lessons more practical and interesting; gave students greater opportunities to verify results and make links between spreadsheet formula, quadratic functions and graphs. In spite of its potential, the study recognized that for spreadsheet to be effective in teaching mathematical concepts, a mix of direct instruction and hands-on activities should guide the lesson development and delivery.*

KEYWORDS: Spreadsheet, Teaching, Education, Students, Quadratic Functions

INTRODUCTION

The importance of mathematics in the development of a country cannot be underestimated as it plays a major role in the economy and the social life of its people. Due to its importance the government of Ghana is committed to ensuring the provision of high quality mathematics education. In spite of government efforts, learning mathematics has not undergone much change in terms of how it is structured and presented and among other reasons has resulted in consistently low achievement levels among mathematics students in high schools (e.g. see Mullis, Martin, & Foy 2008; Ottevanger, Van den Akker, & de Feiter, 2007). Ottevanger et al. (2007) indicated that the most frequently used strategy in mathematics classrooms is the teacher-centred (i.e chalk and talk) approach in which teachers do most of the talking and intellectual work, while students are passive receptacles of the information provided. According to Ottevanger et al. (2007) this type of teaching is heavily dominated by teachers (while students are silent), involves whole class teaching, lots of notes being copied, and hardly any hands-on activities. In most instances, teachers rush to cover all the topics mechanically in order to finish on time for examinations rather than striving for in-depth student learning (Ottevanger et al., 2007). Such teacher-centred instructional methods have been criticized for failing to prepare students to attain high achievement levels in mathematics (Hartsell, Herron, Fang, & Rathod, 2009). For example in Ghana, this approach

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has resulted in general detest for mathematics by most students leading to their poor performance both in the national (e.g. West African Senior Secondary Examination, WASSCE) and international (Trends in International Mathematics and Science Study, TIMSS) examinations (Anamuah-Mensah, Mereku & Asabere-Ameyaw, 2006; Anku, 2005-2006; Djangmah & Addae-Mensah, 2012; UNESCO, 2004). Fletcher (2005) referred to this teaching approach as the transmission model of learning in which teachers view learners as empty vessels easily filled with knowledge, as opposed to a teaching approach that appreciates that students are much more actively involved in constructing their own knowledge.

Consequently, the emphasis on teaching mathematics in a way that is understandable to both mathematics educators and students has been on the rise in the recent past. Numerous studies reiterate the impact of ICT use on the development of mathematical concepts in students and on their' achievements (Beauchamp & Parkinson, 2008; Bottino & Robotti, 2007; So & Kim, 2009). This study has a focus in this direction; to determine the effect of teaching mathematics with ICT in the context of Senior High Schools (SHSs) in Ghana. In particular, the study will compare using spreadsheet as an instructional tool as against the conventional approach in teaching quadratic functions to evaluate their effectiveness on the performance of students. The technology used in this context was spreadsheet application software for mathematics since it is readily available in SHSs (Agyei & Voogt, 2011), user friendly and has the potential of supporting students' higher-order thinking skills in mathematics (Niess, Sadri & Lee, 2007). The choice to focus on quadratic functions among other topics in mathematics was also informed by literature; several studies have shown that students have learning difficulties when it comes to teaching and learning of functions particularly quadratic functions (Clement, 2001; Dubinsky and Harel, 1992; Eraslan 2005; Looney, 2004; Maharaj, 2008; Zazkis, Liljedahl & Gadowsky 2003).

Some Conceptual Difficulties Students Encounter Learning Functions

One topic in mathematics in which students have learning difficulty which results from poor methods of teaching is quadratic functions (Dubinsky & Harel, 1992; Eraslan, 2005). These students' learning difficulties in quadratic function are reported in numerous studies.

Eraslan (2005) for example identified fours cognitive obstacles students face in learning of quadratic functions. These cognitive obstacles are: (1) lack of making and investigating mathematical connections between algebraic and graphical aspects of the concepts, (2) the need to make an unfamiliar idea more familiar, (3) disequilibrium between algebraic and graphical thinking, and (4) the image of the quadratic formula or absolute value function. Eraslan remarked that students lack the ability to make and investigate mathematical connections between algebraic and graphical aspects of the quadratic functions.

Clement (2001) identified that definitions and images of function and the relationship between them transferred from graphical to algebraic form are perhaps most difficult for students (Clement, 2001). Different studies have shown that both in the algebraic and the graphical form, the concept and representation of images and pre-images are only partially understood (Dubinsky & Harel, 1992; Eraslan 2005; Looney, 2004; Maharaj, 2008). The studies (Dubinsky & Harel, 1992; Eraslan 2005; Looney, 2004; Maharaj, 2008) reiterate that students find sketching graphs of quadratic functions difficult and confusing though graphing of functions is an essential component of the study of quadratic functions. Eraslan, (2005) therefore reported that in teaching quadratic functions, students must open up to linked

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concepts such as turning points, intercepts, and the effects of the parameters of the quadratic functions.

In their study, Zazkis, Liljedahl and Gadowsky (2003) examined secondary school students and secondary school teachers (practicing and pre-service teachers) explanations regarding a task on translation of a function, focusing on the example of the parabola $y = (x - 3)^2$ and its relationship to $y = x^2$. The participants' explanations focused on attending to patterns, locating the zero of the function, and the point-wise calculation of function values. The results confirmed that the horizontal shift of the parabola is inconsistent with expectations and counterintuitive to most participants. Zazkis, Liljedahl and Gadowsky (2003) found that students who have been taught quadratic function prior to the study indicated that the graph of $y = (x - 3)^2$ will appear three units to the left of graph $y = x^2$ instead of three units right of $y = x^2$ as shown in Figure 1.

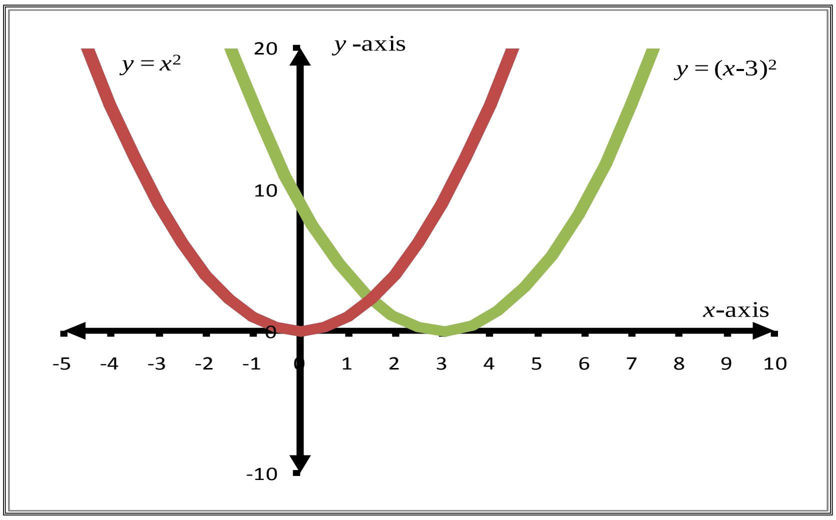

Figure 1: Graph showing the translation of $y = (x - 3)^2$.

Some of the teachers in the study expressed similar conceptual difficulty. For example Zazkis, Liljedahl and Gadowsky reported that:

> *All the teachers participating in this study have sketched the graph of $y = (x-3)^2$ correctly. However, for the practicing teachers it was an immediate and effortless recall from memory, the way one would recall, rather than derive, a basic multiplication fact. Pre-service teachers needed a few minutes of thinking and checking. It was evident that for some pre-service teachers the horizontal translation of a parabola was not in their immediate repertoire of knowledge, but the location of the graph was derived correctly and without major effort* (Zazkis, Liljedahl&Gadowsky, 2003, p. 441).

Such similar problems can be distinguished in the Ghanaian SHS context. Instances of these are found in the national exams explained in the West African Senior School Certificate Examination (WASSCE) Chief Reports (West African Examinations Council (WAEC), 2007; 2008). For example in 2007, the Chief Examiners' Report stated that while students showed improvement in handling questions on topics such as series, binary operations and

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binomial theorem, the students showed weakness in handling questions on factorizing quadratic equations of the form $ax^2 + bx + c = 0$ where $a \neq 0$. Further, it was reported that an appreciable number of students could not use basic concept on equal roots (i.e. $b^2 - 4ac = 0$) of a quadratic function to solve quadratic equations. An example was when students were asked the following question:

> *The roots of the quadratic equation: x^2 -2(3k+1)x+7, where k is a constant, are equal. Find the values of k (*WAEC, 2007, p. 60).

The report indicated that many students exhibited different difficulties in solving this problem. The 2008 report further reiterated that students had conceptual difficulties in sketching quadratic graphs and determining the roots of quadratic equations using the graphical method (WAEC, 2008).

The discussion above seems to suggest that one underlying premise contributing to the learners' difficulty in developing their conceptual understanding well in quadratic functions is the way the topic is structured and presented. Thus, the emphasis on teaching functions in a way that is understandable to students should be a concern to mathematics educators. Monaghan (2005) identified that the use of technological software aids to represent the concept of functions in terms of the strong linkage among the representational 'trinity' of functions: "numerical, symbolic and graphical" representation. In this study, Excel-specific spreadsheet application software has been adopted as an Instructional tool to explore the effect of teaching quadratic functions with technology on performance of SHS students.

Potential of spreadsheet for teaching mathematics

Spreadsheets have been around since the early 1980s and, although not designed as an educational tool, have been used in mathematics classrooms since they first became available (Jones, 2005). Tubbs (2012) described that of all the technological tools, spreadsheets probably have the most uses in the mathematics classroom. Niess, Sadri and Lee (2007) recognized advantages of using spreadsheets for solving complicated problems, motivating students, and providing opportunities for students to extend problems to additional hypothetical situations. According to Niess (2005), spreadsheets offer dynamic modeling capabilities that lead toward their use as a mathematical problem solving tool with the capacity for engaging students in higher-order thinking skills that supports them in exploring beyond initial solutions. Agyei (2013) pointed out that spreadsheet instructional approaches has the tendency to support constructivist pedagogical approach where students explore and reach an understanding of mathematical concepts by concentrating on problems solving process rather than on calculations related to the problems as a result. According to Niess et al. (2007) teachers who are able to design and enact spreadsheet lessons engage their students in critical thinking to explore mathematical concepts and processes for accurate analysis. Jones (2005) indicated that one way to help learners move from a non-algebraic to an algebraic approach is through work with spreadsheets. He explained that in using such a tool, learners appear to be able to learn more readily to express general mathematical relationships using the symbolic language in the spreadsheet environment as compared to using paper and pencil. Dettori, Garuti and Lemut (2001) suggested that while the use of spreadsheet may lead learners to solve problems using "trial and improvement" under the guidance of the teacher, they can come to understand what it means to solve an equation even before being

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able to handle equations. Rojano (1996) showed more evidence of how the judicious use of spreadsheets can lead to algebraic understanding of learners.

Liang and Martin (2008) reported on how Excel spreadsheet was used to enhance SHS students' understanding of some difficult and important calculus-based mathematical principles. They reported that Excel spreadsheet can greatly simplify the interpretation of pure calculus principles and can substantially reduce students' misunderstanding in applying calculus principles in solving quantitative business problems.

In spite of spreadsheets' potential to support higher-order thinking skills and the strong advocacy to integrate it in the teaching, teachers in Ghana do not make use of this tool to guide students in learning mathematics. Classrooms in Ghana are still characterised by the talk and chalkboard illustrations (also referred to as the traditional method) which have received lots of criticism because of its heavy emphasis on the teacher. With the preponderance of this 'traditional' method of mathematics instruction in Ghana coupled with students learning difficulty in quadratic functions, one possible contemporary strategy for improving instruction and student learning could be adopting empirical instructional practices such as the use of ICT. This study sought to explore the potential of spreadsheet as an instructional tool on students' learning outcomes in quadratic functions. In the study, spreadsheet instructional method was compared to the conventional method (defined as the 'traditional' existing approach with less direct instruction by teacher and active student learning engagement opportunities) to evaluate the effect of the approaches on students' performance.

The authors preferred to use the conventional method in this paper to help tradeoff the numerous disadvantages of using the traditional method. In doing so, it would be easier to ascertain the impact of the spreadsheet approach in the study.

The Research Approach and Question/ Hypothesis

The study was conducted in the context of the two different SHSs in Ghana and adopted a non-randomised quasi-experimental research design in which both quantitative and qualitative data were used. To investigate the impact of the spreadsheet-supported lessons on students' outcomes, a pre-post test experimental control group design was used. Two intact classes from the two schools were employed because randomisation was practically impossible since all the lessons were conducted during the schools' regular instructional time. Therefore, randomly selecting some students from the class while leaving others out was unethical; it was important to ensure that the entire students in the class benefited from the lessons. The choice of the class which had the spreadsheet supported lessons treatment was guided by the scores of an achievement test conducted for both classes in quadratic functions before the study. The class which showed a relatively low significant score was purposefully selected to receive the spreadsheet-supported treatment. This was to help in evaluating the effectiveness of the treatments.

The main research question that guided the study was: What is the impact of using spreadsheet as an instructional tool on senior high school students' performance in quadratics functions? In answering the question, the following Null Hypotheses were addressed:

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H_0: Spreadsheet as instructional tool has no effect on the performance of students in quadratic function.

H_0: The conventional method approach of instruction has no effect on the performance of students in quadratic functions.

H_0: There is no significant difference between the performance in quadratic functions of students taught with spreadsheet method and those taught with conventional method.

The lesson delivery for both groups spanned a period of 6 weeks and required the researchers to teach students once in one and a half hour- lesson per week. The lessons were meant to update the students conceptual understanding of some topics on quadratic function including: properties of quadratic functions in polynomial form, sketching quadratic curves, increasing/decreasing and positive/negative parts of quadratic functions, quadratic in factored form, quadratic in the vertex form and nature of the roots of quadratic equations. The guided discovery, a mix of direct instruction and hands on activity teaching approach was used to deliver the lessons for both groups of students. Hmelo-Silver, Duncan and Chinn (2008) indicated that such guided inquiry approaches do not substitute content for practices; rather they advocate that content and practices are central learning goals.This means that the lessons taught in this study were less teacher-centred as they made use of students' worksheets to promote hands-on activities, small group exercises to promote healthy interactions among students, interactive discussions on readings, class assignments and projects. The striking difference that existed in the approaches between the two groups had to do with the use of ICT tools- LCD projector, desktop computers and a laptop (PC). Whereas in the experimental group (spreadsheet method group), lessons were executed with 'interactive demonstrations' in a spreadsheet environment in which the technology was used as a tool to help students explore mathematical concepts and perform authentic tasks, the control group (conventional method group) made use of the talk and chalkboard illustrations to provide explanations and examples without the support of any ICT tool. In all, the same 6 lessons were taught for each of the two groups. Lessons for both the control and experimental group were facilitated by the same instructor. One of authors of the paper acted as the instructor while the other acted mainly as a coach and observer.

METHODOLOGY

Participants

Seventy four (74) students of average age 16 years in SHS 1 who participated in the study, were from 2 different high schools. The schools were purposively selected for the study to ensure that they belonged to the same category based on rankings by the Ghana Education Service. This was to ensure that all other factors that could affect the result of this study, except for the approach of teaching were held constant. One intact class consisting of 32 students (16 males and 16 females) participated in quadratic spreadsheet supported lesson, while the other intact class consisting of 42 (25 males and 17 females) were taught the same lessons with the conventional approach and served as the control group.

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Instruments

Teacher-made Achievement Test

For each of the two groups taught, a test was developed by the authors to determine student learning outcomes. The items on the teacher-made achievement test were constructed based on the lessons taught and the learning objectives of the SHS mathematics curriculum. The test was tailored to emphasize useful information about the students' knowledge of the learning objectives and the quadratic lessons taught in the given instructions. The test contained thirty multiple choice questions and five essay-type questions. The test was reviewed by an expert and based on suggestions; items were revised accordingly to improve the face and content validity of the instrument. The Kuder-Richardson 20 formula (K-R 20) reliability coefficient of the multiple choice items was 0.809 while Cronbachs' alpha reliability coefficient for the essay test items was 0.762. The same test was administered twice (before the first lesson and after the last lesson) for both the experimental and control groups to help ascertain the impact of the Instructional approaches. Thus, the scores of the test was meant to provide not only evaluations of the knowledge levels of individual students, but also information about how students in the different groups compare mastery or non-mastery of the full range of the specific lessons taught during the instruction.

Interview

To explore students' experiences with the use of spreadsheet in learning quadratics functions, interviews were conducted after the spreadsheet supported lesson. Eight of the students who took part in the spreadsheet supported lessons were involved in the interviews. This was done mainly after the post-test. Interview data was meant to provide in-depth elaborations for data collected through the achievement test.

Researcher's Logbook

The researchers' log book was used to maintain a record of activities and events occurring during the classroom implementation of lessons.

Data Collection and Data Analysis Procedures

To analyse the data, descriptive statistics, paired sample *t*-test and analysis of covariance (ANCOVA) were used for the achievement test whereas interviews were transcribed and coded using data reduction technique (Miles & Huberman, 1994). In-depth analysis of items from the achievement test was also done by the researchers. Information recorded in the logbook was analyzed qualitatively using data reduction technique (Miles & Huberman, 1994).

RESULTS

Students Learning Outcomes

A major question dealt with in the study was weather the different Instructional methods had any impact on students' learning outcomes. Students' responses in the pre-post achievement test delineated the impact of each of the instructional method on students learning outcomes.

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Mean Gains of the Students Taught with Spreadsheet Instructional Method (SIM)

Table 1 shows that out of a score of 45, the mean scores of the achievement test before and after the use of the spreadsheet were 9.812 (*SD* = 4.610) and 27.094 (*SD* = 3.325) respectively. The results also showed that an overall significant product - moment correlation (r = 0.55, p = 0.001< 0.05) was strong indicating that students' pre- test score had a strong correlation with their post test scores.

Table 1: Pre-post Test Scores of Students Taught with SIM (*N* = 32)

Test	Min. score	Max. score	Mean	*SD*
Pre-test	4	15	9.182	4.610
Post-test	18	38	27.094	3.325

In spite of the strong positive correlation, differences exist between the pre-post-tests scores. Figure 2 shows the difference between the scores in terms of distance travelled.

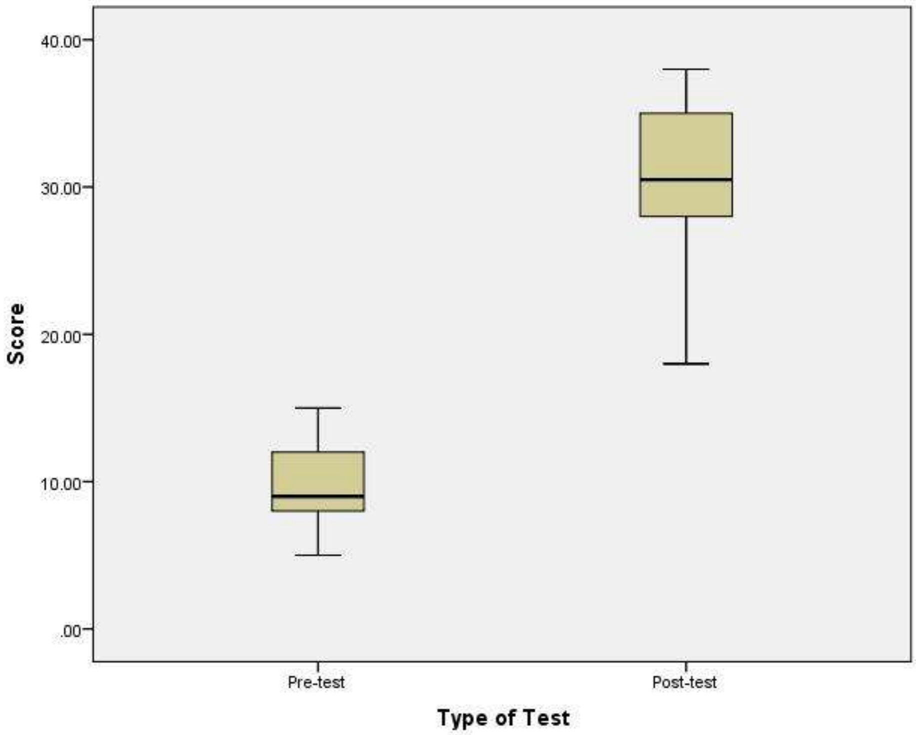

Figure 2: Box plot of pre-post test scores of students taught with SIM

The substantial difference observed seems to suggest how much impact the SIM might have had on the students' learning. Although this is expected, it is worth knowing whether this distance travelled was significant. A paired sample *t*-test was therefore used to test the null hypothesis at 5% significance level that H_0: Spreadsheet as instructional tool has no effect on the performance of the students. The results revealed that the difference in performance was significant [sig. (0.0001) $< \alpha = 0.05$]. The eta square statistic (0.956) indicated a large effect size.

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This is a clear indication that students progressed in their understanding of quadratic functions after the lessons. Apparently, the use of the spreadsheet instructional approach gave students greater opportunity to explore quadratic concepts better by helping them to make links between spreadsheet formula, algebraic functions and graphs. Pre-post analysis of items from the achievement test confirmed this. For example it was observed that most students were unable to plot quadratic functions during the pre-test. In the post-test assessment however, most student sketched the graphs accurately. What was intriguing was that the students sketched these graphs without plotting them in the traditional way (that is merely using a series of calculations to generate the shape of the graph). Thus, they demonstrated an understanding of the effects of the various parameters on the behaviour of the graphical representation. Not only did the students demonstrate understanding in the graphing of quadratic functions but they answered the multiple choice questions that involved higher order thinking which prior to the lesson they were unable to do. Responses from their interview questions also reiterated that the spreadsheet method helped them to learn better. The following were some of the responses provided when they were asked to enumerate how spreadsheet helped them to explore properties of a quadratic function:

> …I *see the shape of the graph as I drag the slider. I noticed that when the coefficient of x^2 is negative the graph is a maximum curve and when it is positive the graph is a minimum. Sir, it also helped me know that when the value of a is zero the graph become a straight line (S1).*

> *It helps me to picture the graph. In the examination, when I am given a function like* $y = -x^2 + 4x + 2$, *I can picture it in my mind before I draw it on graph sheet* (S2)

The analyses here seem to suggest that hands-on activities alongside the spreadsheet demonstrations helped the students to construct and reconstruct concepts of quadratic functions. This made them to reach deeper understanding of the concepts of quadratic functions.

Mean Gains of the Students Taught with Conventional Method (CM)

A second Hypothesis explored the impact of the CM approach. The hypothesis was:

H_0: There is no effect on the performance of students taught with the conventional method. Table 2 shows the descriptive statistics of the scores for the students before and after the use of the CM.

Table 2: Pre-post Test Scores of Students Taught with CM (*N* = 42)

Test	Min. score	Max. score	Mean	*SD*
Pre-test	4	20	12.405	4.169
Post- test	9	32	22.131	4.170

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The mean scores of the achievement test before and after using the CM to teach were 12.405 (*SD* = 4.169) and 22.131 (*SD* = 4.170) respectively indicating an increase in the achievement test. Figure 3 shows the difference between the pre-post-tests scores of the distance travelled for this group of students.

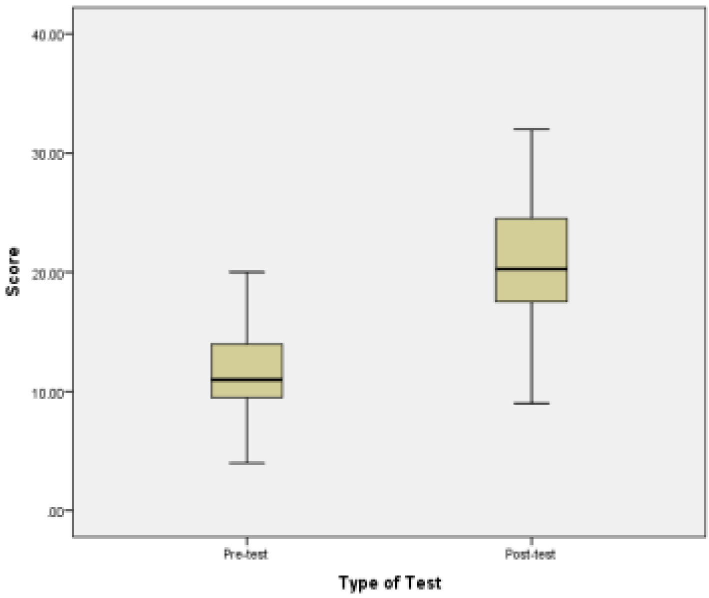

Figure 3: Box plot of pre-post test scores of students taught with CM

A paired sample *t*-test at 5% significant level indicated that the difference in performance was significant [sig. (0.0001) $< \alpha = 0.05$]. The eta squared statistic (0.812) indicates a large effect size which suggests a substantial difference in the achievement test scores obtained. This is an indication that the students' performance had increased. Although this would be expected in a normal lesson after instruction, the pronounced pre-post test difference is worth noting. This result is an indication that a well-planned CM of teaching can improve students' performance in learning quadratic functions.

The lessons made use of series of activities that students engaged in. In each lesson there was a well-structured activities spelled out by the teacher on the students' worksheet to be executed in groups. Thus the delivery approach which involved a mix of teachers direct instruction and appropriate learner scaffolding practices, promoted conceptualization and construction of knowledge. This suggests that the teachers' role is critical in designing and enacting lessons to be student-centred. Their roles should include prompting and facilitating discussion, focusing on guiding students by asking questions and designing activities that will lead learners to develop their own conclusions on mathematical concepts.

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Comparing Performance of the Students Taught with SIM and those taught with CM

This study also explored the differences in students' cognitive outcomes in quadratic functions with respect to the instructional method used.The null hypothesis: *There is no significant difference between the performance of post test scores between students taught with SIM and those taught with CM at 5% significance level* was addressed. In examining whether there was significant difference in the performance between the post-tests for the two groups, ANCOVA was used to adjust the pre-test scores statistically to compensate for the 2.593 point difference between the two groups. Thus, the pre-test scores of the achievement test were used as the covariate in the analysis. Table 3 presents the result of the test of differences between the two groups.

Table 3: Performance of Students taught with SIM and CM (N = 74)

Group	No. of students (N)	Pre-test scores		Post-test scores		ANCOVA		
		M	SD	M	SD	*F*	*p*-value	Eta Squared
CM group	42	12.405	4.169	22.131	4.170	67.854	0.0001	0.489
SIM group	32	9.812	4.610	27.094	3.325			

The results showed significance difference in the post-tests [F (1, 71) = 67.854; sig (0.001) < α = 0.05] in favour of the SIM. The box plot also confirms that the distance travelled in terms of performance is higher for students in the SIM group (see Figure 4).

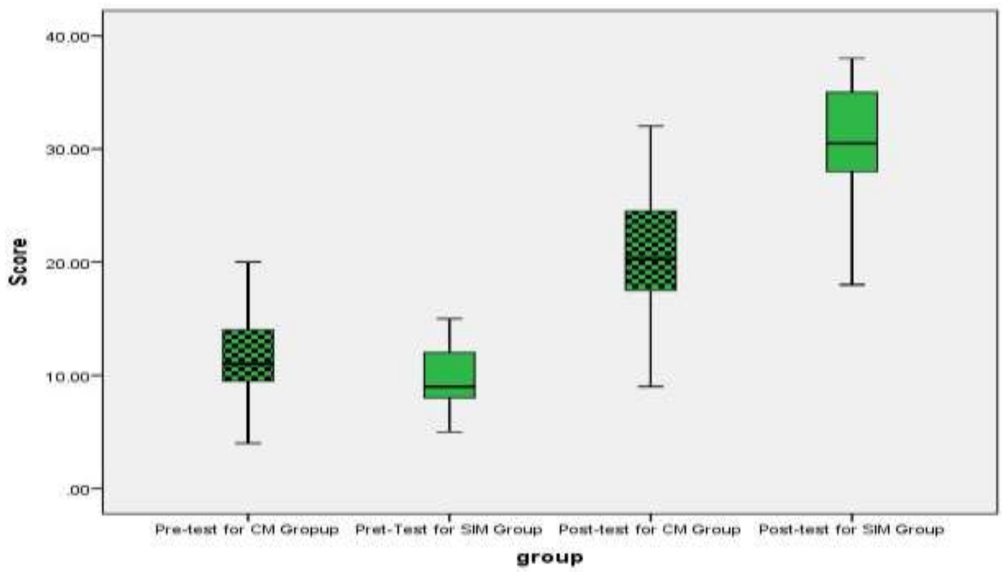
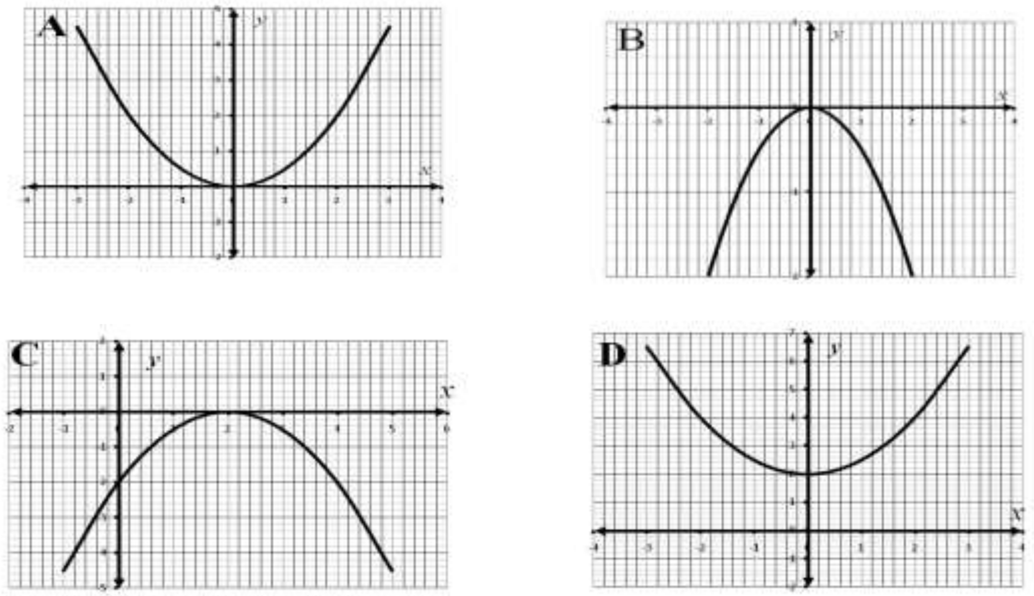


Figure 4: Box plot showing the performance of students in both groups

The eta squared value of 0.489 indicates that the magnitude of the difference between the mean score performance is large (Pallant, 2001). Analysis of individual items of the post-tests gave a better picture of the findings reported on Table 3.

For example, the analyses give an indication that students who learned under the spreadsheet environment were able to make connections between numeric, algebraic, and graphic representations of quadratic functions better than their counterparts who used the CM approach. This was revealed in the analyses of questions which required students to demonstrate understanding of the effects of the parameters *a*, *b* and *k* on the quadratic function, y = $ax^2 + bx + k$. An example is reported on ***Question* 9** of the achievement test:

Which of the following graphs is the graph of $y = 0.5x^2$?



This *question* required students to transfer their knowledge of the nature of the parabola for the algebraic function ($y = ax^2 + bx + k$) to that of $y = 0.5x^2$. By comparing the two functions, they were to use the given numeric values a=0.5, b=0 and k=0 to determine the features of the parabola for the graph $y = 0.5x^2$ and select the best option from the 4 given graphical representations. Thus, based on the numeric values, students were expected to determine the orientation of the parabola, determine the position of the vertex and the height of the parabola. The results from the analysis showed that out of 32 students in the experimental group who answered this question, 26 representing 81.3% were able to determine the right answer from the list of options whiles 28 out of 42 (66.7%) of students in the control group had it correct. Apparently, the use of the spreadsheet unlike the CM, gave students greater opportunity to make links between spreadsheet formula, algebraic functions and graphs, analyse and explore number patterns which promoted their concept formation much better.

The analyses on the **question 21** of the achievement test showed similar result.

21. Which of the functions is the final transformed graph of y = x^2 *if it moves down 3 units and 2 units to the right.*

A. $y = (x - 2)^2 + 3$

B. $y = (x - 2)^2 - 3$

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C. $y = (x + 2)^2 + 3$

D. $y = (x +2)^2 – 3$

Here the students were expected to compare the options to the quadratic function in the vertex form, $y = a(x – p)^2 + q$. They were to use the numerical values for the parameters a, p and q to determine the appropriate algebraic function. In doing so, it was important for the students to visualize how movements in the original graph y = x^2 affect the behaviour of the parabola and connect to the exact values of the parameters. Once students have this understanding, they could easily link the resulting transformation (arising from movements in the original function: y = x^2) to the appropriate function that will be formed.

It appeared that most students in CM group experienced some difficulty integrating and applying the appropriate knowledge in doing the task although this had been explained to them during the lesson. Only 11 out of 42 (26.2%) of the students in that category answered this question correctly while a majority of 26 out of 32 (81.3%) answered it successfully from the SIM group. Consequently, the opportunity offered in the spreadsheet environment in which students in that category explored and observed multiple representations of the graph y = a(x – p)2 + q when the parameters were altered influenced their thinking and practices. Thus, while students from the SIM group were able to fall on the spreadsheet experiences to develop deeper connections between algebraic functions and their graphs, students from the CM group did not enjoy this benefit.

Another observation made in the item analyses was the difficulty portrayed in solving questions that applied to real life situations especially by students in the CM group. An example is reported on the analyses of student performance on ***Question 16*** of the achievement test. The question was:

An athlete throws a javelin. The equation below describes the path that the javelin takes: $h = -4t^2 + 30t + 2$ *where h is the height of the throw in metres and t is the time taken in seconds. Calculate the time that it will take the javelin to reach the maximum height.*

A. 3.75 s

B. 2.55 s

C. 1.35 s

D. 0.45 s

The question required students to apply their knowledge of equation of the line of symmetry, $x = \frac{-b}{2a}$, (which passes through the maximum height of the parabola) to determine the time the javelin takes to reach the maximum height. Only 13 out of 42 (31.0%) of the conventional method group could solve this problem correctly. Whiles more than 50% of the students from the CM were unable to solve this question, 87.5% (28 out of 32) of the spreadsheet instructional method group showed success in solving this problem. This seems to suggest that the SIM group showed mastery of applying knowledge from lessons taught to realistic settings as compared to their counterparts in the CM.

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Perceived Benefits of Spreadsheet Use

As was observed in the SIM lessons, the teacher used the spreadsheet to develop mathematical concepts to support students' understanding. For instance, while it was difficult for the teacher in the CM class to demonstrate that as the absolute value of *a* (the coefficient of x^2) decreases, the graph of $y = ax^2 + bx + k$ widens and vice versa as the absolute value of *a* decreases, it was easier for students to explore and conceptualize this in the SIM class. The spreadsheet helped to demonstrate different values of *a* and their corresponding graphs on the same spreadsheet at the same time, enhancing the conceptualization of the concept (see Figure 5).

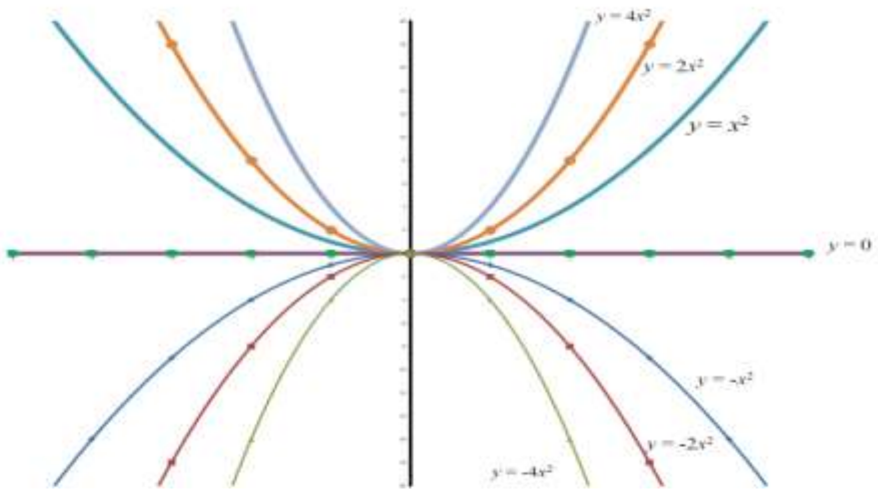

Figure 5: Snapshot of a SIM Lesson showing the graph of y = ax^2.

Similarly, it was also easy for students in the SIM group to illustrate the nature of a quadratic graph by altering the value of *a* (the coefficient of x^2) to obtain a maximum (when *a* is less than 0) or minimum (when *a* is greater than 0) as shown in Figure 5.

Interview data from the students supported the contention that, the spreadsheet use exhibited the potential to improve teaching, learning and achievements in the mathematics lessons. Most of the students explained that it was easier for them to observe the behaviour of different graphs spontaneously. Thus, the spreadsheet made it very fast for them to toggle among multiple graphs while exploring the properties of the quadratic functions. The students also reiterated a number of other benefits they observed using the SIM. They indicated that the spreadsheet provided an opportunity for them to work actively in their small groups performing different activities; data entering, observing and recording the changes the graphs and solving problems. They indicated that the SIM helped their teacher to explain concepts much better and made lessons more practical and engaging.Table 4 below enumerates various reasons that contributed to the usefulness of spreadsheet given by the students.

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Table 4: Student Perceived Usefulness of Spreadsheet in Learning (N = 8)

Students' responses	Number of students	Percentage (%)
Spreadsheet makes lesson more interesting	8	100
Spreadsheet makes lesson more practical	6	75
Spreadsheet makes lesson very easy to understand	7	88
Spreadsheet enhances visualization	6	75
Spreadsheet helps to plot many graph within a short time.	7	88

Among the reasons given, the students were very enthuse by the new way of learning with technology which generated active interactions among them, made the learning interesting and motivated them to develop their own knowledge in higher concepts. Some students had the following to say:

Yes, I like the spreadsheet approach. I like this approach because it makes lesson more interesting and practical. It has helped me to understand the properties of quadratic functions much better (S2)

The spreadsheet helped us to know the truth. When a group member and I did not agree on the answer we used the spreadsheet to tell the answer. It is interesting to learn in this way… (S6).

Despite appreciating the importance of the spreadsheet in developing their concepts much better, the students encountered some challenges in learning with the spreadsheet. The most pronounced challenge had to do with the basic ICT skills (such as entering data, clicking, dragging the slider etc) the students lacked. As a result, some students had initial difficulty working with the Excel window to explore the mathematical concepts. An example was reported in a conversation between the Researcher (R) and a student:

***R:** What difficulties did you encounter using the spreadsheet to learn the quadratic function?*

***S5**: Hmm…..(she paused, thinking). Okay, initially our graph was not responding when we entered the numbers into the cell. We (referring to the group) were finding it difficult to enter the values because it was our first time.*

Although, students reported that they later became conversant with the Excel window and overcame the challenge somehow in the course of the lessons, the analysis here suggests that for more effective teaching and learning with spreadsheet, an orientation programme which will prepare students and provide them with the basic ICT skill to use the tool is important.

DISCUSSION

This study aimed at exploring the impact of spreadsheet as an instructional tool on students' learning outcomes in quadratic functions. The study compared the use of Spreadsheet Instructional Method (SIM) and the Conventional Method (CM) to evaluate the effect of

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these approaches on students' performance in quadratic functions in a context in which mathematics learning have been deep-rooted in teacher-centred approaches of teaching. Both approaches employed a mix of direct instruction and hands-on activities but with different emphases.Whereas lessons were executed with 'interactive demonstrations' in a spreadsheet environment for the SIM lessons, the CM made use of the talk and chalkboard illustrations to provide explanations and examples without the support of any ICT tool.

The results of the study showed that the students reported significant levels of growth in performances for both the SIM and CM; however, students involved in the SIM performed much better than their counterparts in the CM. What was intriguing was that, most students in the SIM lessons' understanding shifted from viewing spreadsheet as a tool of reinforcement to thinking and speaking about it as a tool for developing and constructing their own mathematical knowledge. For instance, it was observed in the study that as the students developed their knowledge and basic skill with spreadsheets, they were able to alter and vary parameters of the quadratic functions within the cells of the spreadsheet window, motivating them to experiment, discover and discuss among themselves the behaviour of the quadratic function.

The results also showed that the spreadsheet allowed for easy investigations into the nature of graphs of quadratic functions, providing a visual link between the graphs of quadratic functions and their algebraic equations. This made it easy for students to match graphs of quadratic functions to their respective algebraic equations on worksheet. Thus, just as reported by Agyei (2012; 2013) and Agyei and Voogt (2014; 2015), using the spreadsheet gave the students greater opportunity to verify results and consider general rules, make links between spreadsheet formula, quadratic functions and graphs, analyse and explore number patterns and graphs within a shorter time, allow for many numerical calculations simultaneously, helping them explore mathematics concepts and apply knowledge from lessons taught to realistic settings.

The study supported the contention (Agyei 2013; Liang and Martin, 2008 & Drier, 2001) that when spreadsheet is fully utilised in classroom, it enhances effective teaching and learning, promoting open-ended exploration of mathematical concepts to support constructivist teaching and learning approach. Adoption of spreadsheets both as a tool for instruction and learning mathematics content in this study was central to a successful intervention which promoted better performance of students learning under this environment. The spreadsheet environment appeared useful to engage the teacher in the design of learning activities to support students in different learning related activities such as: viewing and discussing presentations, collecting data (e.g. on orientation of graphs), making predictions of graph locations, collaborating in teams to explore the properties of quadratic functions and presenting work to peers for assessment. This variety of learning activities offered the teacher opportunity to orchestrate student learning in various ways (cf. Drijvers, Doorman, Boon, Reed & Gravemeijer, 2010). For instance the teachers' visual representations of mathematical functions allowed for immediate feedback, allowing learners to concentrate more on mathematical relationships rather than on the mechanics of construction. Also the teacher was able to demonstrate a wide range of examples of graphs by changing variables in cells (on the spreadsheet) without having to draw them physically; learners were able to explore many graphs in a shorter time, giving them greater opportunity to consider general rules and test and reformulate hypotheses (Agyei 2013). This is the kind of pedagogical

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reasoning (cf. Webb & Cox, 2004) that teachers need to undertake in their planning and teaching of ICT-enhanced lessons.

The results of the study seem to highlight the importance of the guided discovery technique which was used in this study as a necessary contribution to students' learning of quadratic functions. This evidence is seen not only with the SIM approach (as reported in the significant gains of their Pre-post test scores), but more so with the CM approach. The guided discovery technique employed unlike the existing traditional method prompted clearly defined roles for both students and teachers. Students worked collaboratively in groups, had the opportunity to evaluate their own work and that of others sharing their evaluations. The role of the teacher depicted him more as a facilitator than a dispenser of knowledge; managing the context and setting and assisting students in developing mathematical concepts through activities. This seems to have contributed to students learning and imparted on their performance. Consequently, the study advocates that a guided discovery strategy is significant in developing instruction to support mathematics lessons with technology. According to Hmelo-Silver, et al. (2008), such an approach provides the learner with opportunities to engage in scientific practices of questioning, investigation, and argumentation as well as learning content in a relevant and motivating context.

CONCLUSION

In spite of the potential of Spreadsheet as an instructional tool to enhance mathematics conceptual understanding as demonstrated in this study, the authors call attention to further opportunities for teachers to develop their knowledge and skill about the affordances and use of spreadsheet applications to explore mathematics concepts to improve teaching and learning of the subject. Thus, the study contends that, if spreadsheet is to be included as tools for learning mathematics, then teachers need opportunities to develop their personal knowledge and skills in using spreadsheets for exploring and learning mathematics. They need support in redesigning the mathematics curriculum to include spreadsheets as tools for exploring mathematics while also guiding their students' development of knowledge and basic skills with spreadsheets (Niess et al., 2007). The study also calls attention to further opportunities for students to experience learning about the affordances of spreadsheet applications to explore further topics and concepts to improve teaching and learning of mathematics.

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