Asian Journal of Contemporary Education
ISSN(e): 2617-1252
DOI: 10.55493/5052.v8i1.5064
Vol. 8, No. 1, 33-41.

Effectiveness of GeoGebra on Botswana TVET students' performance on linear equations

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Article History
Received: 22 November 2023
Revised: 1 March 2024
Accepted: 15 March 2024
Published: 3 May 2024

Keywords
GeoGebra
Linear equations
Performance
Traditional teaching approach
TVET.

ABSTRACT

The purpose of this study was to investigate the comparative effects of using GeoGebra software and traditional teaching approaches on the performance of TVET students in linear equations. The study followed a quasi-experimental design with a non-equivalent group consisting of pre- and post-test measures. The population of the study consisted of TVET learners from 14 Brigades in the southern region of Botswana. Using the convenience sampling technique, two TVET institutions (n=41) participated in the study. One institution formed the experimental group, whereas the other formed the control group. The study did not employ random participant selection, as the control group and the experimental group comprised pre-existing, intact classes from the participating institutions. GeoGebra software was used in the experimental group, while the control group was taught using the traditional approach with no technology incorporation. Similar pre- and post-tests were administered to both groups to measure the comparative effects of each teaching method on the performance of learners. A constructivist theory framed the study. A t-test was used to analyze the data with $\alpha = 0.05$, and the findings showed a significant difference in the mean scores between the control group and the experimental group ($t = 2.188$, $p = 0.008 < \alpha$) in the post-test. These results indicated that students in the experimental group outperformed those in the control group. Overall, the results of this study showed that GeoGebra enhanced student performance in linear equations as compared to traditional methods of teaching.

Contribution/ Originality: The focus of this study was on TVET, which is a sector of education in Botswana that has, since its inception, received very little research attention and consequently a dearth of literature. The findings of this study contribute immensely to the limited literature, especially in the teaching and learning of mathematics.

1. INTRODUCTION

Botswana, like many other countries, has shown commitment to the integration of Information, Communication and Technology (ICT) in education. This commitment is evidenced by the development and implementation of policies geared towards the diversification of learning environments through the use of technology. The Republic of Botswana (1994) highlights the necessity for the integration of modern technology in all educational contexts. Furthermore, the National ICT Policy of 2009, referred to as the Maitlamo National Policy for ICT Development, advocates for transforming ICT use in the country by providing efficient delivery of research outputs through effective use of ICT and appropriate ICT infrastructure to support research collaboration (Maitlamo, 2007). Recently, the Government of Botswana has embarked on a Fourth Industrial Revolution Digital Transformation Strategy, otherwise known as SmartBots. SmartBots is based on the National Vision 2036 goal, which aims to put Botswana in a strong position within Africa and the world as a "Smart Society" with a broader use of technology (Heckel, 2022).

Computer technology provides extensive opportunities for supporting the learning of mathematics in schools. There is little doubt that computer technology is now regarded as a promising educational tool that brings about new innovative practices in education. The exploration of the possible benefits of practical use of computer technology, particularly GeoGebra software, in mathematics classrooms at Technical, Vocational Education and Training (TVET) in Botswana forms the focus of this study. GeoGebra, created by Hohenwarter, Jarvis, and Lavicza (2009), is a dynamic mathematics software that combines computer algebra systems (CAS) and dynamic geometry systems (DGS). GeoGebra enables students to examine the relationship between symbolic and graphical representations of linear equations by observing more than one representation on the same screen. Manipulating one of them and examining the changes in the others are also possible with the software. The study aims at understanding how GeoGebra software impacts students' performance in linear equations as compared to traditional methods of teaching

1.1. Problem Statement

In Botswana, the integration of technology in classroom settings is still not adequately practiced, even though there have been several Government initiatives that seek to advocate for the implementation of the fourth industrial revolution, which speaks volumes about the digitalization of educational settings. It goes without saying that properly designed digital educational activities that relate to learner's immediate interests and real-life scenarios in learning domains have the potential to impact efficient and effective learning. Many mathematics teachers and their students in Botswana primarily use traditional technology tools, such as scientific calculators, for basic mathematics calculations. Where available, only a few teachers use desktop computers for data storage and the display of statistical information. The nature at which technology is currently used in the mathematics classroom makes it unlikely to develop student understanding, stimulate their interests, or increase their proficiency in mathematics (Batane, 2013; Leteane & Moakofhi, 2015; Mhlanga, 2018).

The motive behind this study is the persistently low performance in mathematics at TVET institutions. Angrist et al., (2014) found that a significant number of students in vocational institutions in Botswana did not understand basic arithmetic operations and mostly made trivial algebraic mistakes in their assessments. The issue of low mathematics performance is further narrated by Carnoy, Chisholm, and Chilisa (2012), who state that the average overall pass rate in quantitative methods, arithmetic, and general mathematics, which are all compulsory subjects in the various courses offered in Technical and Vocational institutions, has over the years been less than 50 %. . The narrative of this presumption of this study was that the undesirable mathematics performance emanates from a lack of modernization of mathematics teaching and learning through technology integration.

The findings of this study provide insight into the contribution of dynamic mathematics software to teaching and learning linear equations and how technology-based instruction influences students' achievement in mathematics classrooms. The study also has great potential to inform teachers and educators about students' learning processes, particularly those related to using the GeoGebra software in mathematics. Instruments that were used for the purpose of data collection in this study followed appropriate quality assurance and therefore may be considered as examples for teachers who have concerns about technology usage in the classroom. Consistent with the Vygotskian perspective, the role of social interaction in the learning process (Vygotsky, 1978) became more evident during the data collection of the study. The findings will not only contribute to the mathematics education literature but also provide teaching implications for teachers, curriculum developers, and educational policy makers. In this regard, the main purpose of this study was to investigate the effectiveness of using GeoGebra on students' performance in linear equations. Further, the study aimed at investigating if the incorporation of GeoGebra in the teaching and learning of linear equations surpasses the traditional method of teaching and learning in terms of student performance. Specifically, the study aimed to comparatively measure the statistical significance of teaching linear equations using GeoGebra and the traditional teaching approach on the performance of TVET students on the topic of linear equations.

1.2. Research Question

The study addressed the following research question:

What is the comparative impact of using GeoGebra versus the traditional approach on the pre-test performance of students on linear equations?

1.3. Null Hypothesis

1. There is no significant difference between the pretest mean scores of the control group and the experimental group.
2. There is no significant difference between the posttest mean scores of the control group and the experimental group.
3. There is no significant difference between the pretest and posttest scores of the control group and the pretest and posttest scores of the experimental group.

2. LITERATURE REVIEW

Significant research indicates a positive impact of computer-assisted instruction on student's mathematics performance. Shadaan and Leong (2013) conducted an experimental design study using a pre-and post-test to evaluate the success of students learning using the GeoGebra software. The study was a twelve hour course held for a period of two weeks involving two eighth grade classes. It was observed that computer based activities can efficiently be used in the learning process, and the GeoGebra software encouraged higher-order thinking skills. The software was also observed to have a positive effect on motivating students towards learning and retaining their knowledge for a longer period of time. A recall test a month later confirmed this. In another similar study, Bhagat and Chang (2015) found that the incorporation of GeoGebra in teaching and learning improved Grade 9 boys interests in mathematics. Using GeoGebra software, students not only extended their learning beyond the teacher's assigned tasks, but also demonstrated happiness and engagement in the lesson. The teacher was also able to identify students who faced challenges in such a setting and did not engage in the lesson; therefore, it was suggested that further strategies need to be incorporated to motivate most students.

Herceg and Herceg-Mandic (2013) conducted a study on two groups of students. One group used applets only, while the other used GeoGebra software and applets. The study tested how to incorporate computer-based learning to reduce the working process of numerical integration. The results of this study showed that the GeoGebra experimental group gained more knowledge and skills than the control group. This study also suggested that GeoGebra is helpful for students who face difficulty solving mathematical problems since they do not have to spend so much time solving by hand. According to Milovanovic, Obradovic, and Milajic (2013), dynamic software improves students' understanding of mathematics; students were able to explore and form conjectures and therefore had better overall scores.

Doktoroğlu (2013) purposed to construct the concept of a parabola with the relationship between its algebraic and geometric representation by using GeoGebra. A learning environment supported by GeoGebra, including four phases, was prepared, and the lesson was implemented in one class hour. GeoGebra was used as a presentation tool, and students examined the algebraic and geometric representation of a parabola in the fourth phase. The 11th grade level class, including 23 students, was videotaped during this hour. The students' important reactions were reported and interpreted. As a result, the four-phases learning environment supported by GeoGebra was found to be practical and beneficial in terms of examining some advanced properties of a parabola. In a similar study, Baydaş, Göktaş, and Tatar (2013) also used GeoGebra in their case study to evaluate high school students' views about learning mathematics with GeoGebra. Students learned quadratic functions with GeoGebra. At the end of the study, an evaluation form, including seven open ended questions prepared by the researcher, was administered. According to the results, it was concluded that learning with GeoGebra provided better learning, and it was found to be fun and interesting by the students.

Zulnaidi and Zakaria (2012) conducted another research study involving the use of GeoGebra. They examined the effects of GeoGebra use on students' conceptual and procedural knowledge of functions. The study sample was composed of 124 high school students. The study used a quasi-experimental, non-equivalent pretest-posttest control group design. The results revealed a significant difference between the groups. It was concluded that GeoGebra improved high school students' not only conceptual knowledge but also procedural knowledge. In addition, it was claimed that GeoGebra helped students understand the relationship between conceptual and procedural knowledge.

Granberg and Olsson (2015) conducted a study to determine the effects of using the dynamic software Geometer's Sketchpad (GS) in the teaching and learning of graph functions. Students in Form Six at a Malaysian secondary school participated in this study. A quasi-experimental design using intact sampling was employed. A significant difference was observed in the achievement of the experimental group as compared to the control group, as the mean score of the experimental group was higher than the mean score of the control group in the post test. This study concluded that GS positively impacted student achievement and attitude towards learning function graphs.

The effects of spreadsheets and Autograph on the achievement and self-efficacy of seventh grade students were investigated by Karakus and Aydin (2017). Three instructional methods, which were spreadsheet-based instruction, Autograph-based instruction, and traditionally based instruction, were randomly assigned to three classes. Activity sheets, including the same questions but in different directions with respect to the instruction method, were prepared. The content of the questions included equations, symmetry, coordinate planes, graphs of linear equations, and solving systems of linear equations by the graphing method. Students in the spreadsheet-based and autograph-based instruction classes worked on the questions using spreadsheets and autographs individually without any guidance. Traditional-based instruction group students also worked on the same questions, but they did not use any technological devices. The mathematics achievement test, mathematics self-efficacy scale, and computer self-efficacy scale were administered both before and after the treatments. According to the analysis of covariance results of the mathematics achievement test, the autograph group students and traditional group students performed better than the spreadsheet group students. In addition, no significant difference was found between autograph and traditional group students' test scores. Moreover, autograph students' mathematics self-efficacy test scores were significantly greater than those of traditional group students, and there was also no significant difference between autograph and Excel group students' scores or between Excel and traditional group students' scores. Additionally, researchers found a significant correlation between self-efficacy scores and mathematics achievement scores.

The effectiveness of using technological tools in mathematics classrooms has been demonstrated in many experimental studies that have been reviewed. GeoGebra software has been used in these studies conducted on high school and college level students. Most of the studies reviewed showed evidence of the positive effects of using Geogebra software on both students' achievement and attitudes towards mathematics. However, the literature on the use of GeoGebra at TVET institution, especially in Africa and, most importantly, Botswana, for the teaching and learning of linear equations is still very limited. The findings of the reviewed articles have predominantly reflected European and American contexts. There is little evidence of similar research efforts in Botswana, particularly in light of the major differences between western societies and local societies. Some differences exist in the mathematics curricula, school structure, and policies regarding the recruitment and training of school teachers. Therefore, the scarcity of studies of this nature on Botswana TVET students formed part of the motive for this study to base its focus, particularly on TVET students.

2.1. Theoretical Framework

The study draws upon the constructivist perspective. The constructivist philosophy is based on the preposition that learners should be actively involved in the processes of thinking and learning (Ornstein & Hunkins, 2009). Cobb, Yackel, and Wood (1992) describe constructivist learning as an active construction and the representational view of the mind, whereby learners modify their internal mental representations to construct Mathematical relationships that mirror external representations to them. Similarly, Woolfolk Hoy (2012) describes constructivism as a philosophy that emphasizes the active role of learners in constructing their own knowledge by building understanding and making sense of information. Complementing these views, Korenova (2017) maintains that in constructivism, learners actively take in knowledge, connect it with previously assimilated knowledge, and make it their own knowledge by constructing their own interpretations. That is to say, within a constructivist approach, learners are actively involved in generating meaning or understanding of their own through the processes of (re)inventing, modifying, structuring, applying, and internalizing information. Learners connect new knowledge with old knowledge as they construct understanding, and critique their ideas and those of others while interacting with the real world. In a constructivist classroom, the teacher provides learners with resources and activities that ensure they are actively involved and participate while constructing their own knowledge and understanding.

In this study, the constructivist approach to teaching and learning was adopted, as participants were expected to become more actively involved in building their own dynamic Mathematical understanding of linear equations as they interact with the computers, each other, and with any other learning tool. The experimental group of learners used a computer program, GeoGebra, to solve linear equation problems, while the control group used traditional conventional teaching methods besides a computer program to solve linear equation problems. The computer was expected to be a teaching and learning tool that minimizes the dominance of the teacher in the learning setting while increasing individual learner participation in accordance with the principles of constructivism, as compared to Conventional Teaching Instructions (CTI). Also, because of the one-on-one situation provided by the computer, learners were expected to retrieve and modify their prior knowledge while interacting with each other and with their learning tool, and internalize the constructed new knowledge as they solved linear equation problems.

3. METHODOLOGY

This study followed a quantitative approach and employed a quasi-experimental design with a non-equivalent group. The population for the study consisted of all TVET learners from 14 TVET institutions located in the southern region of Botswana. A convenient sampling procedure was used in the study, and the sample was $n = 21$ at the institution that formed the control group and $n = 20$ at the institution that formed the experimental group. A pre-test and post-test were used to collect data on the impact of Geogebra on student performance as compared to the traditional method of teaching and learning.

3.1. Results Presentation and Analysis

Table 1 and Table 2 show the group statistics and the independent t-test on the pretests of both the control and experimental groups, respectively. The t-value significance was tested at $p < 0.05$. The results shown in Table 1 and Table 2 aim at addressing Null hypothesis 1: There is no significant difference between the pretest mean scores of the control group and the experimental group.

Table 1. Pre-test group statistics.

Pre-test	N	Mean	Std. deviation	Std. error mean
Experimental group	21	8.19	2.136	0.466
Control group	20	8.35	1.725	0.386

Table 2. Independent samples test on pre-test.

Pre-test	t-test for equality of means				
	t	df	Sig. (2-tailed)	Mean difference	Std. error difference
Equal variances assumed	-0.262	39	0.794	-0.160	0.608

Table 1 shows that the control group obtained a mean score of 8.35, while the experimental group obtained a mean score of 8.19. Table 2 indicates a mean score difference of 0.16 with a t-value of 0.262. The P-value is 0.794 ($P > 0.05$). Also, the critical value, as observed from t- statistics table (2.022), is greater than the t-value (0.262). Both of these comparisons indicate that the difference in the mean score of the two groups is not significant, which calls for a failure to reject the null hypothesis, which states that there is no significant difference in the pretest mean score of both the control and experimental groups. This result illustrates that both the students in the control and experiment groups were similar in abilities before treatment was administered.

Table 3 and Table 4 show the group statistics and the independent t-test on the post-test of both the control and experimental groups, respectively. The t-value significance was tested at $p < 0.05$. The results shown in Table 3 and Table 4 address Null hypothesis 2: There is no significant difference between the posttest mean scores of the control group and the experimental group.

Table 3. Group statistics on post-test.

Post test	N	Mean	Std. deviation	Std. error mean
Experimental group	21	11.81	2.040	0.445
Control group	20	10.10	1.832	0.410

Table 4. Independent samples test on post-test.

Post-test	t-test for equality of means				
	t	df	Sig. (2-tailed)	Mean difference	Std. error difference
Equal variances assumed	2.818	39	0.008	1.710	0.607

Table 3 shows that the control group obtained a mean score of 10.10, while the experimental group obtained a mean score of 11.81. Table 4 indicates a mean score difference of 1.7 with a t-value of 2.818. The P-value is 0.008 ($P < 0.05$). The critical value from the t-statistics table (2.0226) is less than the t-value (2.818). Both of these comparisons indicate that the difference in the mean score of the two groups is significant. These call for a rejection of the null hypothesis and hence the alternate hypothesis, which states that there is a significant difference in the post test mean score of both the control and experimental groups. This finding illustrates that the students in the experimental group performed better in the post test by learning linear equations using GeoGebra than the control group, who were taught using the traditional teaching method.

Table 5 shows the results of the paired sample t-test on the pretests and posttests of both groups. The t-value significance was tested at $p < 0.05$. The results shown in Table 5 address Null hypothesis 3: There is no significant difference between the pretest and posttest scores of the control group and the pretest and posttest scores of the experimental group.

Table 5. Results of the paired sample t-test on the pretests and posttest of the control and experimental group.

Posttest score-pretest score		Paired differences			t	Sig. (2-tailed)
		Mean	Std. deviation	Std. error mean		
Pair 1	Control group	1.750	1.410	0.315	5.552	0.000
Pair 2	Experimental group	3.619	1.161	0.253	14.286	0.000

The results in Table 5 above show that the mean score difference between the pretest and posttest scores of the control group was 1.750 as compared to the mean score difference between the pretest and posttest scores of the experimental group, which was 3.619. For pairs 1 and 2, the P-value obtained was 0.000 ($P < 0.05$), indicating that the differences between the pretest scores and posttest scores of both groups were significant. For Pair 1, the critical value from the t-statistics table (2.093) is less than the t-value (5.552). Also, for pair 2, the critical value from the t-statistics table (2.0859) is less than the t-value (14.286). These call for a rejection of the null hypothesis. From the above results, it can be seen that students gained knowledge and understanding from both approaches, which is shown by a significant improvement in the scores of both groups. It appears, however, that students in the experimental group gained more knowledge, as seen by their higher mean difference or improvement as compared to the control group.

4. DISCUSSION AND CONCLUSION

Results of the pre-test Table 3 showed that the control group obtained a mean score of 8.35, while the experimental group obtained a mean score of 8.19. Table 4 indicated a mean score difference of 0.16 with a t-value of 0.262. The P-value was 0.794 ($P > 0.05$), indicating that the difference in the mean score of the two groups was not significant. Statistically speaking, the experimental and control groups, on average both had more or less the same conceptual understanding of linear equations as portrayed by the results of the pre-test at the beginning of the experiment. This is to say that it can be concluded that both the control and experiment groups were similar in abilities before treatment was administered. The results support the notion by Hallberg, Cook, Steiner, and Clark (2018) that pretest outcome plays a special role in bias reduction compared to other covariates, as well as the hypothesis that two pretest waves are preferable to one.

Results of the post-test Table 3 shows that the control group obtained a mean score of 10.10, while the experimental group obtained a mean score of 11.81. Table 4 indicates a mean score difference of 1.7 with a t-value of 2.818. The P-value is 0.008 ($P < 0.05$), indicating that the difference in the mean score of the two groups is significant. The results of the post-test indicate an improvement in performance in both the control and experimental groups, which indicated that learning took place despite the use of different teaching methods. However, GeoGebra did make a bigger difference regarding general performance (as measured by the post-test), both in absolute and differential terms.

Results from the paired sample t-test (Table 5) show that the mean score difference between the pretest and posttest scores of the control group was 1.750 as compared to the mean score difference between the pretest and post test scores of the experimental group, which was 3.619. For both pair 1 and pair 2 (see Table 5), P-value obtained was low ($P < 0.05$), indicating that the differences between the pretest scores and posttest scores of both groups were significant. This meant that from the pre-test to the post-test, learners in the experimental group improved more than learners in the control group. In the pre-test, the standard deviations of both groups of learners were almost the same, (see, Table 1). However, in the paired sample t-test (see Table 5), the standard deviation of the control group (1.410) was bigger than that of the experimental group (1.161). This is an indication that the marks of the experimental group were closer together than those of the control group. In other words, the gap between learners who understood and those who did not understand was bigger in the control group as compared to the experimental group. Therefore, learners who learned through GeoGebra performed better than those who learned the traditional way.

It can be seen that students gained knowledge and understanding from both approaches, which is shown by a significant improvement in the scores of both groups. It is evident, however, that students in the experimental group gained more knowledge, as seen by their higher mean difference or improvement as compared to the control group. The results of the current study complement those of Fernández-Cézar, Garrido, and Solano-Pinto (2020); Childress (1996); and Brown (2018). In their studies, they also concluded that Computer-aided instruction was more effective than CTI in improving learner performance. Therefore, GeoGebra software may be argued to be a possible solution to the poor performance of learners in Geometry, and Mathematics, as observed by Ngobese (2013), Gweshe and Dhlamini (2015), Cassim (2012), and Mansukhani (2010).

In this study, students were able to experience a hands-on method of learning, which had a positive effect on enabling them to understand the concepts better than just being passive learners. The software also gave the teacher and students the opportunity to work through the concepts together through exploration and visualization. This encouraged a more interactive teacher-student interactional environment where everyone worked as a team to guide, help, and assist one another to reach the required goals. The cognitive aspect of learning linear equations was represented by visualization and understanding. Overall, GeoGebra is an effective tool for assisting the teacher and students in the mathematics classroom to achieve the principles of constructivist learning. Based on the findings of the current study, it is highly recommended that teachers be encouraged to use GeoGebra software in teaching Mathematics. This should be coupled with research to establish better findings to conclusively ascertain whether GeoGebra does actually have an effect on the learning of broader mathematical concepts and on different levels of students.

Funding: This study received no specific financial support.
Institutional Review Board Statement: The Ethical Committee of the University of Botswana, Botswana has granted approval for this study on 30 March 2017 (Ref. No. UBR/RES/IRB/001).
Transparency: The author states that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
Competing Interests: The author declares that there are no conflicts of interests regarding the publication of this paper.

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