Article

The Effectiveness of Using the Geometer's Sketchpad to Enhance TVET College Level 4 Students' Understanding of Circle Geometry

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Abstract

The integration of technology in the instructional process has been at the centre of attention in mathematics classrooms since the outbreak of the novel coronavirus (Covid-19) which was declared a global pandemic on 11 March 2020. This article reports on a study that used a quasi-experimental design to investigate the effectiveness of using the Geometer's Sketchpad (GSP) to enhance Technical Vocational Education and Training (TVET) college Level 4 students' understanding of circle geometry. Using quantitative research methods, random sampling was used to select a sample of 70 participants from a population of 133 TVET college Level 4 mathematics students. The participants were randomly divided into an experimental and a control group. This article hinges on Lev Vygotsky's concept of the zone of proximal development (ZPD) for learning as a potential solution in enhancing circle geometry instructional practices. Pre-test and post-test instruments consisting of 10 multiple choice questions and 10 problem-solving questions on tangents, chords and proofs were used to gather the data. The data was then analysed using inferential statistics in which the SPSS version 27 determined the statistically significant difference between the experimental and control groups. The findings indicated a significant increase in the experimental group's understanding of properties of tangents using the GSP. Further, the questionnaire participants revealed that using the GSP enabled an engagement based on the principles of cooperative and collaborative learning. Therefore, the researchers recommend the use of the GSP within the TVET college sector, among students with limited circle geometry knowledge who intend to further their studies in geometry-related courses.

Keywords: circle geometry; Geometer's Sketchpad; teaching, learning; effectiveness; Technical Vocational Education and Training

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Introduction

The Curriculum and Assessment Policy Statement (CAPS) for mathematics for South Africa's secondary school learners emphasises the need for teachers to assist learners to develop problem-solving and cognitive skills and investigate solutions to real life problems (DBE 2011). Although not explicitly stated, the general aims outlined in CAPS suggest the use of technology to mediate mathematics teaching and learning processes where learners are guided to use tools to explore mathematical concepts relationally. Researchers (Benning, Linsell and Ingram 2018; Hartono and Halim 2020; Shadaan and Leong 2013) report that high quality developed digital content can improve student achievement, engagement, and critical thinking skills. In addition, the dynamics of students in the 21st century require educators to engage in advanced pedagogical competencies (Putra et al. 2021). However, lack of technological knowledge and skills impede the abilities of both educators and students to use technology effectively in the classroom (Agyei and Voogt 2012). Learners' dispositions on their knowledge, beliefs and attitudes are essential attributes that should be considered for the dynamic nature and effective integration of technology into the mathematics curriculum. The Subject and Assessment Guidelines for Technical Vocational Education and Training (TVET) mathematics prescribe that students learning geometry are required to use spatial skills and properties of shapes and objects to identify, pose and solve problems creatively and critically (DHET 2016). This suggests that during geometry learning, it is important for the students to be able to use their spatial skills to visualise, construct and understand geometric shapes to be able to associate them with theorems (Shadaan and Leong 2013).

In this article, we contend that the integration of technology in geometry instruction is one of the means that can improve the instructional process so that geometry learning objectives can be achieved. Several educational technological tools such as smartboards, scientific calculators, the Geometer's Sketchpad (GSP) and GeoGebra software are freely available for geometry instruction. Thus, we acknowledge that GeoGebra can be used as one tool for studying and understanding two-dimensional shapes. The article focuses on the use of the GSP in learning circle geometry in National Certificate: Vocational (NCV) Level 4 mathematics.

Problem Statement

The novel coronavirus (Covid-19), which was declared a global pandemic on 11 March 2020, exposed the socio-economic disparities in the South African education system. Some of those disparities include unequal teaching and learning environments in TVET colleges. For instance, at the start of level 5 lockdown on 26 March 2020, well-equipped colleges transitioned with ease to online teaching and learning, while the under-resourced schools were left dysfunctional, some relied on textbook learning. When the Covid-19 levels were revised, alternate learner attendance was practised, with 50% classroom capacity to allow social distancing. This suggests that teaching and learning in the majority of TVET colleges across South Africa was predominantly through chalk and talk. This traditional approach to teaching and learning makes it difficult for NCV

Level 4 mathematics students to visualise, construct and justify geometric concepts, especially circle theorems within the prescribed instruction time. However, nationally, all NCV Level 4 students, including those with minimal digital coverage in under-resourced colleges, wrote the same 2020 and 2021 final examinations. Geometry covers 40% of the final year examination and was covered in questions 9, 10 and 11 of paper 2 in 2020 and 2021. Table 1 summarises the national average performance for 2020 and 2021 in Euclidean geometry questions.

Table 1: National average performance in Euclidean geometry questions

Year	Question 9	Question 10	Question 11
2020	45%	43%	43%
2021	56%	24%	34%

Source: Adapted from DHE (2020–2021)

The summary of the students' performance in Euclidean geometry questions in Table 1 indicates that at Grade 12 level, students continue to perform below the expected national levels. Students' lack of cognitive and process skills to understand circle theorems, pre-requisite knowledge, and inappropriate and incorrect reasoning skills are among some of the difficulties that students experience in learning circle geometry concepts (Ngirishi and Bansilal 2019) upon entering TVET colleges. Consequently, circle geometry concepts appear difficult for students to understand. As part of the Department of Higher Education and Training (DHET 2013) curriculum, TVET college Level 4 mathematics students learn geometry that entails nine circle geometry theorems dealing with angles in a circle, cyclic quadrilaterals, and tangents. Circle geometry is a section of Euclidean geometry that includes theorems, their converses, corollaries, and axioms.

Considering the problem stated above, the purpose of this article is to identify the effectiveness of using the GSP to enhance NCV Level 4 students' understanding of circle geometry.

Objective and Research Questions

The main objective of this study was to examine the effectiveness of using the GSP in enhancing NCV Level 4 students' understanding of circle geometry. In addition, the study aimed at identifying if the GSP's instructional approach transcended the traditional textbook approach to learning and determining students' views on learning using the GSP. The research questions were:

1. What is the effectiveness of using the Geometer's Sketchpad in enhancing NCV Level 4 students' understanding of circle geometry?

2. What are NCV Level 4 students' views on the use of the Geometer's Sketchpad in learning circle geometry?

The motive for choosing circle geometry for this study was that circle geometry knowledge builds on knowledge from previous learning (Muzangwa and Chifamba 2012). On transition from high school to college, learners must have acquired basic knowledge of six proof theorems in Grade 12 (WCED 2016). Secondly, circle geometry concept is appropriate for teaching and learning using dynamic software, information about pedagogical approaches to teaching and learning of circles is included in the GSP. The central focus of the zone of proximal development (ZPD) is that a more knowledgeable other (MKO) can enhance students' learning by guiding them through tasks that are slightly above their aptitudes. We will not repeat the considerable evidence pointing to the use of the GSP as a technological tool for enhancing students' mathematics achievement, attitude towards mathematics and technology. Such evidence can be found in abundance (Çelik, Erduran and Eryiğit 2016; Gemechu 2017; Roble 2016). However, none of the extant research was within TVET colleges, therefore there was a need for this study on the effectiveness of using the GSP to enhance understanding of circle geometry by NCV Level 4 students.

In the first part of this article, we provide evidence of the nature and aims of the instructional process in the TVET system. Next, we venture into discussions on the GSP and its usefulness in the teaching and learning of mathematics. Lastly, the ZPD as a theoretical framework that underpinned this study is presented.

Literature Review

In the Fourth Industrial Revolution (4IR) era, it is important to keep up with the technological trends and innovations to meet the 21st century teaching and learning needs. Several countries in the world, including South Africa, base their national education system on knowledge, skills and competencies that are required in various occupations, known as the TVET system (Rusmar 2017). According to Rusmar (2017), the instructional process in the TVET system is aimed at producing students with critical thinking and problem-solving skills; collaboration, agility and adaptability; initiative and entrepreneurialism; effective oral and written communication; and ability to access and analyse information. All these skills require students to have a solid background of mathematical knowledge. In addition, Paryono (2017) asserts that TVET is considered a value-added portion of a general education that integrates technology, sciences, practical skills, attitudes, understanding, and information relating to employment in different economic and social sectors. Moreover, Said, Pavlova and Wheeler (2020) assert that in order to respond to the global mega trends, such as the rising role of technology, climate change and demographic shifts, cognitive, socio-emotional, technical and digital skills are required for 21st century competence. To acquire such skills, students need to learn and think since the knowledge of mathematics is vital (Maron 2016). This means that by registering at TVET colleges, students should acquire the knowledge and skills that are required in the professional world. Hence, the mathematics teaching and learning and instructional activities should be thoroughly prepared to provide students with critical thinking and problem-solving skills.

The Geometer's Sketchpad

The GSP is a leading commercial dynamic mathematics software that includes Euclidean geometry, algebra and calculus in a single package (Greenwald and Thomley 2013). Studies by Güven and Kosa (2008) and Meng and Sam (2013) refer to the GSP as a useful mediation tool in geometry instruction because it provides a learning platform where students explore geometric relationships and conjectures. Its features provide learning opportunities for students to explore, develop and learn three-dimensional geometry including measuring angles, lengths and surface areas onscreen (Ganesan and Eu 2020). In addition, the GSP allows students to manipulate geometric figures and control them intuitively (Oldknow, Taylor and Tetlow 2010). The exploration, creation and manipulation of geometric figures is a good exercise and a springboard that can be used for students to discover and distinguish among geometric figures.

Several studies have been conducted on the use of the GSP in mathematics education. For example, Seker and Erdoğan (2017) assert that the integration of the GSP in mathematics learning is positively associated with student achievement and student sufficiency, since it made learning easy. In addition, Selçik and Bilgici (2013) note that using the GSP in teaching polygons increased student motivation and mediated the learning of basic geometric concepts. Similarly, in a study conducted by Dogan and Içel (2011), it was found that the GSP had a positive effect on students' learning of triangles and Pythagorean theory, which resulted in students being able to retain information in their long-term memory for longer periods. It can therefore be noted that using the GSP enhances the teaching of most mathematics topics.

Theoretical Framework

This article draws on the concept of Vygotsky and Cole's (1978) idea of the ZPD and scaffolding. We noticed that NCV Level 4 students encounter learning difficulties in understanding circle geometry concepts. Since circle geometry concepts cover 40% of the NCV Level 4 mathematics syllabus, under-performance in that section may lead to students failing the subject.

Cognitive development is one of the widely used notions in Lev Vygotsky's cultural–historical psychology. The ZPD continues to draw research interests because of its role in creating instructional frameworks that are aimed at developing students' geometric thinking, as opposed to memorising learnt facts (Coats and McGinn 2019). According to Vygotsky (1987, 86), the ZPD can be thought of in terms of

> the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers.

The ZPD is a constructivist learning approach that is based on the premise that learning happens when learners are actively involved in the process of meaning making and knowledge construction, rather than being passive recipients of knowledge. According to Shadaan and Leong (2013), the distinct features of the ZPD as a constructivist approach to teaching and learning are:

1. Social interaction which occurs when students work together in groups with opportunities for cognitive conflict, which results in common understanding;
2. Student autonomy which happens when students take charge/agency of their learning;
3. Student centred where students' ideas and opinions are considered important than those of the teacher/educator; and
4. A more knowledgeable other (MKO), who provides temporary support to the student during the learning process.

In terms of the ZPD in the learning of circle geometry, more capable students can assist their peers by manipulating the GeoGebra applet and scaffold the gaps in their peers' knowledge. Similarly, when working in groups with a different ZPD, each student may present cognitive conflicts, and through interaction with their peers, they can reach common understanding (Shadaan and Leong 2013). However, in situations that result in cognitive conflicts, there must be a balance of ideas contributed by team members to reach common understanding. This suggests that it is important to have shared views and justifications of opinions to reach mutual understanding. In this way, students' cognitive development improves when new concepts are accommodated in their cognitive schemes.

For the current study, GSP version 5.06 software was used as a scaffold to assist students to reach their ZPD. What is important in the learning process is the availability of the mediating tools that can be used to direct the mind and behaviour (Silalahi 2019). The GSP, which can be thought of in terms of the MKO, acts as a scaffold for mediation and collaboration between the student and the learning content. The MKO is important as a scaffolding tool is important in the development of the students' ZPD. This is in line with Piaget's (1990) theory of cognitive development, which proposes the need to provide formal instruction to assist students to reach a particular developmental stage in order to be able to accommodate and assimilate information at a particular level of cognitive demand. Exploring and manipulating the GeoGebra applets scaffolded and enhanced students' understanding and visualisation of circle geometry.

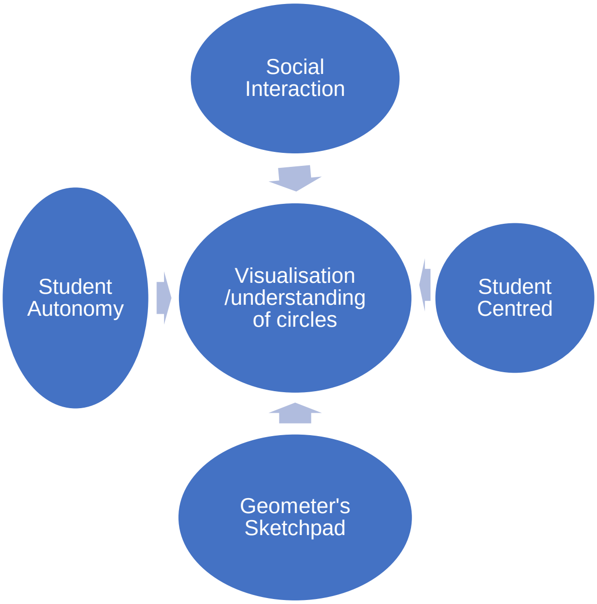

Figure 1: SSSG Theoretical Framework

Methodology

This study was undertaken using a quantitative research approach to examine the effectiveness of using the GSP in enhancing Level 4 TVET students' understanding of circle geometry. The hypothesis testing was undertaken using a quasi-experimental research design, and a questionnaire was used to triangulate the results. The intervention was conducted with the experimental group, while instruction in the control group progressed using the traditional textbook instructional approach. The intervention involved the incorporation of the GSP which was facilitated by the researchers.

Population and Sampling

This study aimed to assess the effect of using the GSP to enhance Level 4 TVET students' understanding of circle geometry. Using a quasi-experimental research design consisting of a pre-test and post-treatment, the study involved 70 participants who were selected using randomised sampling procedures. This was from a population of a cohort of 133 NCV Level 4 students who were registered for mathematics at a TVET college. These were further randomly split into two equivalent groups of 35 each in the experimental and control educational environments. The participants were registered at the same institution, with the experimental and control groups being taught at different campuses. The purpose of separating the control group from the experimental group was to avoid the control group receiving the intervention that may influence outcomes (Robinson et al. 2020). In the treatment phase, the control group was taught circle geometry content using the traditional approach, largely reliant on the techniques and problem-solving procedures of the conventional textbook. However, in the experimental group, the learning of circle geometry was achieved by incorporating aspects of the GSP in which students explored various technological options in the software to solve geometry problems.

Pre-test and post-test instruments consisted of 10 multiple-choice questions and 10 problem-solving questions on tangents, chords and proofs were used to collect the data. Both the experimental and control groups wrote the pre-test to measure their baseline knowledge on circle geometry concepts. The lessons covered circle geometry theorems and applications over a period of four weeks. At the end of the intervention, a questionnaire was administered to elicit the students' perceptions of using the GSP. Using a questionnaire, the experimental group reflected on their innovative learning experiences and the influence of the GSP on their learning of circle geometry. The questionnaire contained 10 items using a Likert scale of 5 = Strongly disagree, 4 = Disagree, 3 = Neutral, 2 = Agree and 1 = Strongly agree. While Shadaan and Leong (2013) used the GeoGebra, the authors used the questionnaire and spoke to the idea of the GSP. The items on the questionnaire were categorised as follows:

1. Views on the use of the Geometer's Sketchpad.
2. Views on how the Geometer's Sketchpad improves understanding.
3. Views on students' communication skills when using the Geometer's Sketchpad.
4. Views on students' attitudes towards learning circle geometry when using the Geometer's Sketchpad.

Table 1: Sample composition

No. of students (Sample)	**Group of students**	**Breakdown of numbers**	**Percentage**
70	Experimental	35	50
	Control	35	50
Total		70	100

Data Analysis

The data from pre-test and post-test was analysed using inferential statistics. The *t*-test was used to test the statistically significant difference between the experimental and control groups. This was done by comparing the mean scores of the pre-test and post-test scores using the Statistical Package for Social Sciences (SPSS) version 27. The data from the questionnaire was analysed using descriptive statistics.

Findings

To answer the research question, the *t*-test was conducted to determine if statistically significant differences existed between the pre-test and post-test mean scores of the experimental and control groups. The findings in this study are presented based on the research question. The first section presents the findings of the *t*-test to determine statistically significant differences between the pre-test and the post-test mean scores of the experimental and control groups.

Table 2: Results of the independent *t*-test of the pre-test of both groups

	Pre-test			
Group	**Mean**	**SD**	***t*-value**	**Sig. (2-tailed)**
Experimental ($n = 35$)	21.74	11.08	.3	.31
Control ($n = 35$)	22.69	11.27		

Note: *t* significant at $p < 0.34$

Table 2 shows that the experimental group obtained a mean score of 21.74, while the control group obtained a mean score of 22.69. The mean score difference between the two groups was 0.95, with a *t*-value of 0.34. The *p*-value of 0.31 ($p < 0.34$) indicated that students in the experimental group and the control group had the same abilities prior to the administration of the treatment in the experimental group. This suggests that the difference in the mean score was not significant. This further implies that participants in the experimental and control groups did not have similar abilities before the treatment was administered.

Table 3: Results of the independent *t*-test of the post-test of both groups

	Post-test			
Group	**Mean**	**SD**	***t*-value**	**Sig. (2-tailed)**
Experimental ($n = 35$)	29.49	19.67	.94	.000
Control ($n = 35$)	25.93	13.56		

Note: *t* significant at $p < 0.94$

Table 3 shows that the control group obtained a mean score of 25.93, whereas the experimental group obtained a mean score of 29.49. The mean score difference between the two groups was 3.56. However, the *p*-value was low ($p < 0.94$), indicating that the difference in mean scores of the experimental and control groups was significant. This finding suggested that participants in the experimental group performed better when the GSP was utilised during instruction than when the traditional approach to teaching and learning was utilised.

Table 4: Results of the paired sample *t*-test

Post-test				
	Mean	**SD**	***t*-value**	**Sig. (2-tailed)**
Post-test score – pre-test score (Experimental group)	19.75	8.59	3.6	.000
Post-test score – pre-test score (Control group)	3.24	2.29		.000

Note: *t* significant at $p < 3.6$

The paired sample *t*-test was conducted to compare the pre-test and post-test of the experimental group with a mean score of 19.75 and standard deviation of 8.59. The results as indicated in Table 4 revealed that the mean score difference between the pre-test and post-test was 3.6 ($p > 0.00$). This indicates that the difference between the pre-test and post-test scores was significant. On the other hand, the mean score for the control group was 3.24 with a standard deviation of 2.29. This finding indicated that there was an improvement in the scores of both groups in learning through the traditional approach and integration of the GSP in learning. However, the students in the experimental group appeared to have a higher mean score when compared to the students in the control group. Thus, the implication was that the GSP improved students' understanding of circle geometry. The results from the students' perceptions of using the GSP are displayed in Table 5.

Table 5: Students' perceptions of using the GSP in learning circle geometry

Item no.	**Statement**	**5 = Strongly Disagree**	**4 = Disagree**	**3 = Neutral**	**2 = Agree**	**1 = Strongly Agree**
1	I like to use Geometer's Sketchpad software.	(14.3%)	(17.1%)	(14.3%)	(34.3%)	(20%)
2	I feel confident when doing activities using Geometer's Sketchpad software.	(8.6%)	(11.4%)	(17.1%)	(40%)	(22.9%)
3	I can think creatively and critically when using Geometer's Sketchpad software.	(8.6%)	(14.3%)	(8.6%)	(48.5%)	(20%)
4	I prefer to learn circle geometry using Geometer's Sketchpad software.	(11.4%)	(11.4%)	(17.1%)	(40%)	(20%)
5	I can visualise and answer questions on	(8.6%)	(14.3%)	(11.4%)	(28.6%)	(37.1%)

	activities that involve Geometer's Sketchpad software.					
6	I benefit a lot during student-to-student interaction with Geometer's Sketchpad software.	(5.7%)	(8.6%)	(11.4%)	(40%)	(34.3%)
7	I feel confident when solving mathematical problems using Geometer's Sketchpad software.	(8.6%)	(14.3%)	(17.1%)	(34.3%)	(25.7%)
8	Geometer's Sketchpad software can assist to improve my understanding of circle geometry concepts.	(5.7%)	(11.4%)	(17.1%)	(37.1%)	(28.6%)
9	I am able to make logical assumptions when attempting proof.	(8.6%)	(8.6%)	(17.1%)	(42.8%)	(22.9%)
10	Geometer's Sketchpad software can help to increase my achievement in mathematics.	(8.6%)	(8.6%)	(14.3%)	(51.4%)	(17.1%)

Table 5 presents the general positive feedback of students' perceptions of using the GSP in learning circle geometry. About 74% of the students mentioned that they benefitted through increased confidence when using the GSP when learning circle geometry. About 70% of the students mentioned that they were engaged during the learning process and were able to visualise circle geometry concepts such as the properties of tangents. In addition, about 68% of the students mentioned that learning through the GSP assisted them in improving their understanding of circle geometry concepts because they were able to engage logically and creatively during question-and-answer sessions. Furthermore, 65% of the students indicated that using the GSP increased their achievement in circle geometry tests as they were able to make connections between previously learnt circle geometry concepts and new learning. However, 32.9% of the students reported that they did not enjoy using the GSP to learn circle geometry.

Discussion

Mathematics teachers can incorporate the GSP as a scaffolding tool during the teaching and learning of geometry, especially circle geometry. The findings of the study showed a statistically significant increase in the experimental group's understanding of the properties of tangents using the GSP. In addition, the questionnaire participants revealed that the use of the GSP enabled an engagement based on the principles of cooperative and collaborative learning. This finding was consistent with the research of Benning, Linsell and Ingram (2018) that designing technology-based mathematics lessons influences mathematics achievement because students become active participants in knowledge construction.

The findings of this study were consistent with several other research studies (Agyei and Voogt 2012; Arbain and Shukor 2015; Ridha, Pramiarsih and Widjajani 2020) on the effects of integrating technology in mathematics learning. These studies reported on the improvement of students' geometry understanding when technology was incorporated during learning, compared to students whose learning used the traditional approach in geometry classes. Improved geometry learning outcomes can be characterised using the constructivism model which is underpinned by the notions of the ZPD (Silalahi 2019), the MKO and scaffolding.

TVET college lecturers may use the ZPD to bridge the gap between what students can do without assistance. According to Vygotsky and Cole (1978), students' thinking and abilities to solve problems fall within the following categories: abilities to solve problems independently; abilities to solve problems with assistance; and those who cannot solve problems with assistance. Those who cannot solve problems even with assistance lie beyond the ZPD. This means that students' ZPD may be improved by using online learning activities that include the GSP and students' collaborations inside and outside the classroom. Circle geometry learning activities that are developed by the TVET college lecturers should start with what students can do independently, taking into consideration the pre-requisite knowledge of circles to connect to students' existing knowledge, with the knowledge that they can acquire under guidance or integration of the GSP. As students continue to learn circle geometry concepts and theorems with the assistance of the GSP, they can perform certain tasks in activities independent of the GSP. The shift that the students gain in understanding helps them to find alternative ways of attempting the problems that they were unable to solve even with assistance and understand the dynamic nature of geometry. Thus, mathematics lecturers as facilitators should be informed about educational technological advancements that can be used in the classroom.

Teacher professional development programmes should constantly advocate for the use of technology when reviewing teaching and learning pedagogies. For instance, the National Council of Teachers of Mathematics (Evans, Leija and Falkner 2001, 21) suggests that

> teachers should use technology to enhance their students' learning opportunities by selecting or creating mathematical tasks that take advantage of what technology do efficiently – graphing, visualizing and computing.

Thus, the use of technology should be one of the key principles that steer teacher professional development programmes.

The findings from the questionnaire revealed that integrating technology during learning helped students to gain confidence in learning circle geometry. This was evident where 74% of the students reported that the GSP was instrumental in enhancing their abilities to answer questions on learning activities. For students to acquire understanding of circle geometry concepts, there must be learning material that enables them to shift within their ZPD to gain deeper understanding of the concepts under study. Thus, the GSP acted as a scaffolding tool to help students realise their ZPD. In addition, the ZPD requires that TVET college lecturers be more knowledgeable in using the GSP in order to assist students to engage with the software successfully.

This finding was consistent with a study by Walan (2020), who reported that technology-based learning activities trigger higher order thinking skills which motivate students to learn. As a result, students were engaged in the lesson and were able to visually explore the properties of tangents beyond what the textbook can offer. However, some students reported less confidence levels when using the GSP. This may be attributed to their limited knowledge on the use of the GSP, which may have resulted in their feeling overwhelmed.

Recommendations and Future Studies

In the current study, the GSP proved to be an effective mediation tool when integrated in the classroom to improve students' understanding of circle geometry concepts. By integrating GSP during learning, collaborative learning took place where students engaged with one another and with the software to acquire the desired understanding. Based on the findings of this study, it is highly recommended that lecturers in TVET colleges integrate the GSP in teaching mathematics, especially among students who enter the colleges with limited knowledge of geometry concepts with the intention of advancing their careers in geometry related disciples. Further research should be conducted to examine whether the GSP is effective in learning of other mathematical topics in other levels in the college.

Conclusion

The GSP was found to be an effective tool in improving circle geometry learning in this study. The educational software acted as an enabler which allowed students to engage hands-on during instruction. This means that TVET college lecturers who teach mathematics, especially circle geometry, may use the GSP to close the gap between what students can do with assistance and what students can do independently. Lifelong learning by every individual is made up of a regulated ZPD sequence that ranges from the assistance of the MKO to self-assistance which happens repeatedly for development of improved capabilities. This sequence fosters interaction among the students themselves, interaction with the GSP, and interaction with the researcher. Interaction with the GSP helps the students to realise their ZPD through the notions of student autonomy, social interaction, and student centeredness. Overall, the GSP is an effective scaffolding tool in mediation between students and the learning content to attain the principles of the constructivism framework. Based on the findings of this study, the researchers recommend that TVET college lecturers and teachers incorporate the GSP in geometry teaching and learning. Further research studies can be conducted to determine the effectiveness of the GSP in other mathematics topics at other levels of learning at TVET colleges.

References

Agyei, D., and J. Voogt. 2012. "Pre-service Teachers' Competencies for Technology Integration: Insights from a Mathematics-Specific Instructional Technology Course." In *Society for Information Technology and Teacher Education International Conference*, 1094–1099. Waynesville: Association for the Advancement of Computing in Education.

Arbain, N., and N. A. Shukor. 2015. "The Effects of GeoGebra on Students' Achievement." *Procedia-Social and Behavioral Sciences* 172: 208–214. https://doi.org/10.1016/j.sbspro.2015.01.356

Benning, I., C. Linsell, and N. Ingram. 2018. "Using Technology in Mathematics: Professional Development for Teachers." Paper presented at the Mathematics Education Research Group of Australasia (MERGA) 41 Conference, Auckland, July 1–5.

Çelik, A., A. Erduran, and P. Eryiğit. 2016. "The Effect of Utilizing the Three-Dimensional Dynamic Geometry Software in Geometry Teaching on 12th Grade Students, Their Academic Success, and Their Attitudes towards Geometry." *Dokuz Eylül Üniversitesi Buca Eğitim Fakültesi Dergisi* (41): 1–16.

Coats, L., and E. McGinn, eds. 2019. "Digital Texts and Textual Data: A Pedagogical Anthology." Accessed April 5, 2022. https://dsl.lsu.edu/nehtextualdata/pedagogical-anthology/

DBE (Department of Basic Education). 2011. "National Curriculum Statement Grades R–12." Accessed April 1, 2022. http://www.education.gov.za

DHET (Department of Higher Education and Training). 2013. "Assessment Guidelines Mathematics NQF Level 4." Accessed April 5, 2022. https://www.dhet.gov.za

Dogan, M., and R. Içel. 2011. "The Role of Dynamic Geometry Software in the Process of Learning: Geogebra Example about Triangles." *Journal of Human Sciences* 8 (1): 1441–1458.

Evans, C. W., A. J. Leija, and T. R. Falkner. 2001. *Math Links: Teaching the NCTM 2000 Standards through Children's Literature*. Englewood: Libraries Unlimited.

Ganesan, N., and L. K. Eu. 2020. "The Effect of Dynamic Geometry Software Geometer's Sketchpad on Students' Achievement in Topic Circle among Form Two Students." *Malaysian Online Journal of Educational Technology* 8 (2): 58–68. https://doi.org/10.17220/mojet.2020.02.005

Gemechu, D. 2017. “The Effect of Geometry Sketchpad on the Academic Achievement of Students: The Case of Bedele Secondary and Preparatory School.” *International Journal of Engineering Sciences and Research Technology* 6 (5): 29–39.

Greenwald, S. J., and J. E. Thomley. 2013. “Using the History of Mathematics Technology to Enrich the Classroom Learning Experience.” In *Electronic Proceedings of the 24th Annual International Conference on Technology in Collegiate Mathematics*, paper S071. Accessed April 5, 2022. http://archives.math.utk.edu/ICTCM/i/24/S071.html

Güven, B., and T. Kosa. 2008. “The Effect of Dynamic Geometry Software on Student Mathematics Teachers’ Spatial Visualization Skills.” *Turkish Online Journal of Educational Technology* 7 (4): 100–107.

Hartono, H., and E. Halim. 2020. “The Effect of Digital Capability on Competitiveness through Digital Innovation of E-Travel Business in Indonesia.” In *2020 International Conference on Information Management and Technology (ICIMTech)*, 615–620. Accessed April 5, 2022. https//ieeexplore.ieee.org/document/9211228

Maron, I. A. 2016. “Priorities of Teaching Mathematics in University.” *IEJME-Mathematics Education* 11 (9): 3339–3350.

Meng, C. C., and L. C. Sam. 2013. “Enhancing Primary Pupils’ Geometric Thinking through Phase-Based Instruction Using the Geometer’s Sketchpad.” *Asia Pacific Journal of Educators and Education* 28: 33–51.

Muzangwa, J., and P. Chifamba. 2012. “Analysis of Errors and Misconceptions in the Learning of Calculus by Undergraduate Students.” *Acta Didactica Napocensia* 5 (2): 1–10.

Ngirishi, H., and S. Bansilal, S. 2019. “An Exploration of High School Learners’ Understanding of Geometric Concepts.” *Problems of Education in the 21st Century* 77 (1): 82–96. https://doi.org/10.33225/pec/19.77.82

Oldknow, A., R. Taylor, and L. Tetlow. 2010. *Teaching Mathematics Using ICT*. London: Continuum International.

Paryono, P. 2017. “The Importance of TVET and Its Contribution to Sustainable Development.” *AIP Conference Proceedings* 1887 (1): 020076. https://doi.org/10.1063/1.5003559

Piaget, J. 1990. *The Child’s Conception of the World*. New York: Littlefield.

Putra, A., S. Sumarmi, A. Sahrina, A. Fajrilia, M. Islam, and B. Yembuu. 2021. “Effect of Mobile-Augmented Reality (MAR) in Digital Encyclopedia on the Complex Problem Solving and Attitudes of Undergraduate Student.” International Journal of Emerging Technologies in Learning (IJET) 16 (7): 119–134. https://doi.org/10.3991/ijet.v16i07.21223

Ridha, M. R., E. Pramiarsih, and W. Widjajani. 2020. “The Use of GeoGebra Software in Learning Geometry Transformation to Improve Students’ Mathematical Understanding Ability.” *Journal of Physics: Conference Series*, 1477: n.p. https://doi.org/10.1088/1742-6596/1477/4/042048

Robinson, K., F. Allen, J. Darby, C. Fox, A. L. Gordon, J. C. Horne, P. Leighton, E. Sims, and P. A. Logan. 2020. “Contamination in Complex Healthcare Trials: The Falls in Care Homes (FinCH) Study Experience.” *BMC Medical Research Methodology* 20 (1): 1–6. https://doi.org/10.1186/s12874-020-00925-z

Roble, D. B. 2016. “The Geometer’s Sketchpad: A Technological Tool Enhancing Junior High School Students’ Mathematics Achievement, Attitude towards Mathematics and Technology.” *American Journal of Educational Research* 4 (15): 1116–1119.

Rusmar, I. 2017. “Teaching Mathematics in Technical Vocational Education (TVET).” *Proceedings of the 1st International Conference on Innovative Pedagogy (ICIP) 2017*. Accessed April 5, 2022. https://www.researchgate.net/publication/323265092_TEACHING_MATHEMATICS_IN_TECHNICAL_VOCATIONAL_EDUCATION_TVET

Said, Z., M. Pavlova, and L. Wheeler. 2020. “21st Century Skills’ Challenges to Postsecondary TVET Institutions in Qatar.” Paper presented at the 14th International Technology, Education and Development Conference, Valencia, Spain, 2–4 March. Accessed November 29, 2022. https//repository.eduhk.hk/en/publications/21st-century-skills-challenges-to-postsecondary-tvet-institutions

Seker, B. H., and A. Erdoğan. 2017. “The Effect of Geometry Teaching with GeoGebra Software on Geometry Course Success and Geometry Self-efficacy.” *OPUS International Journal of Society Studies* 12 (7): 82–97.

Selçik, N., and G. Bilgici. 2011. “The Impact of GeoGebra Software on Student Success.” *Kastamonu University Kastamonu Journal of Education* 19 (3): 913–924.

Shadaan, P., and K. E. Leong 2013. “Effectiveness of Using GeoGebra on Students’ Understanding in Learning Circles.” *Malaysian Online Journal of Educational Technology* 1 (4): 1–11.

Silalahi, R. M. 2019. “Understanding Vygotsky’s Zone of Proximal Development for Learning.” *Polyglot: Jurnal Ilmiah* 15 (2): 169–186. https://doi.org/10.19166/pji.v15i2.1544

Vygotsky, L. S. 1987. “Thinking and Speech.” In *The Collected Works of L.S. Vygotsky* (Vol 1), edited by R. W. Rieber and A. S. Carton, 39–285. New York: Plenum Press.

Vygotsky, L. S., and M. Cole. 1978. *Mind in Society: Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press.

Walan, S. 2020. "Embracing Digital Technology in Science Classrooms – Secondary School Teachers' Enacted Teaching and Reflections on Practice." *Journal of Science Education and Technology* 29 (3): 431–441. https://doi.org/10.1007/s10956-020-09828-6

WCED (Western Cape Education Department). 2016. "WCED Telematics Learning Resource." Accessed November 29, 2022. http://wced.wcape.gov.za/branchIDC/Districts/briefly.html