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Investigation of student's perception learning calculus with GeoGebra and cycle model

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Abstract

Learners in the 21st century need technological support in the learning process because of the advancements made in technology for teaching and learning. A GeoGebra-oriented classroom uses one of these technologies that can be implemented in the classroom. The new developed cycle model implemented in the study and explored the effect of using GeoGebra mathematical software on students' perceptions to using GeoGebra software to learn calculus. A mixed research methodology was employed. In the quantitative part of the study, a closed-ended questionnaires were used by clustering into themes and interview for the qualitative part of the study. The study was conducted at a university in Ethiopia that lasts for four weeks, and the university was selected purposively. The quantitative data were analyzed using SPSS version 27 while the qualitative data were coded into themes and analyzed using computer software ATLAS.ti 9. Students expressed positive perceptions towards the use of GeoGebra for learning differential calculus and 74% of students were satisfied with the preferences of the GeoGebra lesson-oriented course offered in the study while 70% were also interested in scaffolding activities and activities included in the developed model during interventions.

Keywords: perception, calculus, cycle model, GeoGebra, ATLAS.ti 9

INTRODUCTION

Technology has become one of the powerful resources of learning (Machaba & Bedada, 2022). The evolution in using technology in teaching and learning process has grown by leaps and bounds. There was a lot of mathematics software have been developed to aid teaching and learning, including GeoGebra, MATLAB, Geometer's Sketchpad, and Mathematica. Several studies have been carried out on GeoGebra software to study various aspects of learning. GeoGebra has become a tool that can help teachers to design effective instructional lessons. GeoGebra not yet widely used in teaching mathematics in Ethiopia (Bekene, 2020). Although technology has been proven to improve the efficiency of learning. Students' attitudes towards mathematics can be affected by technology. Internationally most of the countries education system are revolved themselves within the fourth educational revolution in which the teaching and learning should be re-shaped. Arango et al. (2015) and Nobre et al. (2016) concur that the use of technologies as an alternative and novel way of teaching and learning calculus may support students' understanding of the abstract and complex theoretical ideas that characterize this field of mathematics. On a practical level, interactive technology such as graphing calculators and mathematics software helps students to visualize change and growth through graphical representations (Arslan et al., 2011; Liang & Sedig, 2010; Moses et al., 2013).

Background of the Problem

Instructional aids used by teachers in the classroom, teacher quality and class management all influence students' attitudes towards mathematics (Yilmaz et al., 2010). Teaching methods are also a factor (Papanastasiou, 2000). One subject that is frequently regarded as challenging by most students is mathematics. Nevertheless, mathematics is a basic tool both for all scientific studies and for real life. Whether

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Contribution to the literature

- Learners in the 21st century need technological support in the learning process because of the advancements made in technology for teaching and learning process with specified instructional technology.
- The study developed new instructional technology named cycle model and implemented it in the study area and explored the effect of using GeoGebra Mathematical software on students' perceptions of learning calculus in using the developed model.
- The study reveals that students expressed positive perceptions towards the use of GeoGebra for learning differential calculus and more satisfied with the activities included within the new developed model during interventions.

one is educated or not, mathematics is part of one's everyday life. Mathematics helps students to articulate concepts in the real world; such articulation poses a challenge for many students at university. The use of multimedia technology in the teaching and learning process can simplify this difficulty (Ayub et al., 2008). Multimedia learning instruction, defined as using presentations (words) and representations (figures) can foster learning by combining verbal and visual representations of complex concepts (Mayer, 2009). The importance of technology in education as a tool and channel of instruction has been recognized (ten Brummelhuis & Kuiper, 2008); however, students' perceptions of the use of technology have received less attention (Li, 2007).

Teaching in Ethiopia is still traditional, and teacher centered. Thus, this study developed a new model known as the cycle model and implemented it in the study area and investigated its fruit fullness for teaching differential calculus by technology in terms of student's perception towards learning calculus by the technology with the use of the cycle model. This study is unique as it developed the instructional model and implemented in the classroom and studied the perception of students towards using both GeoGebra and the developed model.

Objectives of the Study

The general objective of the study was to investigate the effect of the use of GeoGebra mathematical software on university students' learning of calculus. The specific objectives of this study were to investigate students' experiences and perceptions of the use of mathematical software (GeoGebra) in learning calculus concepts.

Research Questions

General research question

What is the effect of GeoGebra on students' proficiency in learning calculus at a tertiary level in Wachemo University using cycle model?

Specific research question

What are students' experiences and perceptions towards using mathematical software (GeoGebra) and cycle model when learning calculus concepts?

LITERATURE REVIEW

Teaching and Learning Differential Calculus

Brief overview of studies on differential calculus

Various conceptualizations of calculus exist, as follows:

1. Calculus is a branch of mathematics that deals with quantities approaching other quantities (Charles-Ogan & Ibibo, 2018).
2. Calculus is a branch of mathematics that deals with how a change in one variable is related to changes in other variables (Nobre et al., 2016).

Tall (2009) describes a calculus course of study as the desire to quantify and express:

1. How things change (the function concept);
2. The rate at which things change (the derivative of functions);
3. How they accumulate (the integral of functions); and
4. The relationship between the two (the fundamental theorem of calculus and the solution of differential equations).

Standard terminology in calculus includes the terms limits, derivatives, and integrations of functions, while the main terms in differential calculus are limits and derivatives of functions. The big ideas in calculus are limits, derivatives, integrals, and fundamental theorem, while the idea of series also features in the generalization of calculus and mathematical analysis (Tall, 2019).

Arango et al. (2015) argue that traditionally explaining differential calculus can be dry and off-putting for students; they believe that the use of technology may render explanations more fruitful. As technology continues to develop at an astonishing pace, teaching and learning calculus becomes more possible and accessible. Technology has migrated from large mainframes to portable desktop computers, calculators, laptops, and notebooks, while manual input of data, arithmetic and the subsequent creation of graphs have been replaced by automated calculations and graphs. This makes technology available anywhere, anytime.

A study conducted in Brazil by Nobre et al. (2016) found that calculus (and the way it was taught) was the primary cause of failure among college and university students. Traditionally, students experience calculus as difficult, hard to understand and daunting; innovative methods and approaches are needed to make teaching and learning of calculus more effective (Charles-Ogan & Ibibo, 2018; Lasut, 2015). As early as the end of the last century, Rochowicz (1996) identified calculus as the subject that prevents many students from completing courses in science and engineering. According to his research, the calculus curriculum was outdated (even then) and needed to be revised to align with a technologically oriented educational curriculum.

The rapid growth of technology in the 21st century is ongoing, and studies on the effect of combining technology and calculus instruction have also increased. Tall et al. (2008) identify the dynamic nature of both technology and calculus as the reason for this increased interest in such research. Recognizing the importance of calculus as the backbone of many science courses, other scholars (Durán et al., 2014; Lavicza, 2010; Mignotte, 1992; Ozgun-Koca, 2010; Robutti, 2010) have argued that technology has the potential to simplify complex calculus concepts and is gaining ground as a research interest.

The potential of technology in education to promote constructivist instruction is particularly appealing. Huang et al. (2019) list the characteristics of constructivist learning, as follows:

1. Instruction is student-centered.
2. Learners actively construct internal psychological representations.
3. Learning comprises the reorganization and reconstruction of old knowledge and the meaningful construction of new knowledge.
4. Learning is not only individualized, but involves language centered social interaction, communication, and cooperation.
5. Learning must be situationally embedded to support meaningful learning.
6. The construction of meaning requires appropriate resources.

Beliefs About Learning and Teaching Mathematics Through Technology

Several qualitative studies of teachers' and students' beliefs about mathematics learning with the use of technology, particularly GeoGebra, have been conducted.

Teachers' beliefs about technology-oriented mathematics classrooms

Teachers' perceptions of effective teaching and their cultural beliefs may influence their instructional practices; these beliefs must not widen the gap between theory and practice (Purnomo et al., 2016).

There is no uniform definition of the term teacher beliefs in the literature. Ertmer (2005) defines beliefs as suppositions, commitments, or ideologies. Variations in teachers' cultural belief systems influence how they view their students, what mathematics should be learned, and how this should be taught (Tirosh & Graeber, 2003). Galbraith and Haines (1998) view beliefs as a way of imitating a certain set of concepts, while attitudes are an emotional reaction to an object, to beliefs about an object, or behavior towards the object such as technology. They view emotion as heated or agitated arousal created by some stimulus. In their review of articles, they found that understanding students' attitudes and beliefs about learning is a crucial step in understanding how the mathematics learning environment is affected by the introduction of computers and other technology to the classroom.

Ernest (1989) identified three main components of teachers' mathematical beliefs: the conception of the nature of mathematics as the basis of the philosophy of mathematics; the structures of mathematics teaching; and the process of learning mathematics. The conception of the nature of mathematics is fundamental as it has an impact on the structure of mathematics teaching and the process of learning mathematics (Speer, 2005; Thompson, 1992). Ernest (1989) reasons that the restructuring of teaching cannot take place unless teachers' beliefs about mathematics, its teaching structure, and its learning process change. In general, teachers' beliefs are regarded as critical to the restructuring of mathematics education (Cooney & Shealy, 1997; Leder et al., 2002; Thompson, 1992). In particular, teachers' beliefs towards technology in the classroom, their beliefs about the potential of their students and teaching mathematics have a decisive impact on the success or failure of the implementation of technology (Windschitl & Sahl, 2002). Teachers who believe in the potential of instructional technology are catalysts for the transformation of teaching mathematics with technology.

Teachers believe that the integration of GeoGebra in their classrooms is timesaving when preparing worksheets, tests, lecture notes and board work. Prepared work can be stored on a web page or the GeoGebra software; teachers can simply change the variables of the object to create a new set of instructional materials. Interactive lectures can also be created using GeoGebra and can be uploaded on the internet (Hohenwarter et al., 2008).

Zakaria and Lee (2012) found that teachers were positive perceptions about the use of GeoGebra as far as its features, tools and commands were concerned. In a quantitative survey, these researchers concluded that technology can be used as an alternative method in mathematics instruction. Tatar (2013) used a mixed-methods approach to investigate the effect of technology, in particular GeoGebra, on teacher perceptions and arrived at the same positive conclusion.

Although educational technology is undeniably beneficial and positively perceived by teachers, Pierce and Ball (2009) found that a lack of time, skills and confidence may hinder its implementation in the classroom. They suggest ways for smooth implementation to overcome such barriers.

Students' beliefs about technology-oriented mathematics learning

Leder et al. (2002) explain that students' beliefs about mathematics are "implicitly or explicitly held subjective conceptions" that they believe to be true and "that influence their mathematical learning and problem solving'' (p. 16). Thompson (1992) states that although the term belief is not clearly defined, it is assumed that the reader knows what is meant in context. In this study, I use the term concerning students' and teachers' perceptions about the use of technology when learning calculus.

Students' attitudes towards mathematics can be affected by technology. Akanmu (2015) found that Nigerian students' attitudes towards mathematics could be linked in a significant way to their knowledge of GeoGebra. Factors that could influence students' attitudes towards the use of GeoGebra include their attitude towards learning mathematics and their knowledge of the technology they will be using to master mathematical concepts (Anthony & Walshaw, 2007; Kele & Sharma, 2014). Anthony and Walshaw (2007) regard students' attitudes towards technology as a central concern when evaluating the impact of technologies on mathematics learning.

Kele and Sharma (2014) found both negative and positive mathematical beliefs among the students in their study and concluded that teachers needed to develop or use new instructional approaches in mathematics instruction to encourage a positive disposition towards mathematics in all students. Mwei et al. (2012) noted that the majority of students developed constructivist learning strategies when exposed to computer-assisted instruction (CAI).

Han and Carpenter (2014) define beliefs about mathematics as the cognitive component of attitude, while feelings (emotions) about mathematics comprise the affective component of attitude (Akinsola & Olowojaiye, 2008). Behavioral responses are the observable elements of attitude that students display when dealing with mathematics (Ingram, 2015). Cognitive and affective components of attitude interact with each other and are both important in learning mathematics (Di Martino & Zan, 2011). Student responses to mathematics instruction, i.e., their mathematical behavior, are the overt expression of the cognitive and affective elements of attitude (Akinsola & Olowojaiye, 2008).

Unsuccessful behavioral attitudes such as negative feelings manifest when students are not confident about mathematics (Di Martino & Zan, 2011). As soon as students observe the importance and value of mathematics in real life, however, they start to engage in learning, gaining confidence and becoming connected (Attard, 2012). Students' beliefs about mathematics influence their achievements, and the cognitive, emotive, and behavioral aspects of attitude are intertwined. This holds also for students' cognition, affect and behavior as far as mathematical software is concerned.

Guiding and scaffolding the effective use of the latest technology in mathematics learning helps students to solve mathematical problems with greater ease (Oldknow et al., 2010). This holds for the complex mathematical topic of calculus (Ayub et al., 2010), as reflected in the improved performance of students who learned calculus through the aid of technology. Two programs, Mastering Calculus Computer Courseware (MACCC) and SAGE software were investigated and their effect on the learning of calculus; however no significant difference in student performance was detected (Ayub et al., 2008).

Hew and Brush (2007) list some barriers that affect the teaching and learning of mathematics through technology, including a lack of resources, negative attitudes and beliefs, institutional restrictions, the complexity of the subject and variations in culture, knowledge, and skills.

Complex mathematical tasks such as visualizing a 3D graph may be difficult for the teacher to demonstrate manually; this is simplified by using technology. Bos (2007) found a better understanding of such concepts among students who used technology than among those not using technology. It may be that such improvements result in altered beliefs about mathematics.

Learning Differential Calculus Using GeoGebra Software

The use of technology in teaching calculus stimulates student participation and motivation by relating subject content and concepts to visualization and experimentation (Nobre et al., 2016). GeoGebra mathematical software provides significant opportunities for meaningful learning and concept formation in calculus, geometry, and algebra at various levels (Tatar, 2013). Ocal (2017) investigated the effect of GeoGebra on applications of derivatives in two calculus classrooms (experimental and control) involving 55 students. Students' conceptual understanding and scores both improved; however, there was no significant difference between the procedural knowledge of the experimental group and the control group. The National Research Council (2001) argues that conceptual and procedural knowledge of mathematics are interrelated components, with the first (conceptual understanding) taking the central position. Procedural fluency can be affected by basic instructional routines and by following steps, algorithms and methods or strategies of calculation and the application of formulae and rules.

In the GeoGebra software-based mathematics classroom, the main task of the teacher is to guide students' work, as the software enables students to explore and discover mathematics concepts by themselves (Preiner, 2008). This idea is consistent with Vygotsky's (1978) classical cognitive constructivist theory which calls for a gradual transformation in the perceptions of the teacher's role from an authoritative source of information (behavioral) to a guide or facilitator of learner's self- propelled exploration (constructivist) (Mwei et al., 2012). Preiner (2008) found that the simple way in which developers of GeoGebra designed the user interface of the software aligns with the characteristics of cognitive constructivism, particularly its visualizing and explorative capabilities, its contribution to multimedia environments for learning and the minimization of cognitive load in learning. Multimedia environments offer new ways of learning and teaching compared to traditional environments (Preiner, 2008).

In summary, studies on the integration of GeoGebra in differential calculus have found positive effects on student performance (Akanmu, 2015; Nobre et al., 2016; Ocal, 2017; Preiner, 2008; Tatar, 2013).

The Challenge of Improved Performance from Teaching with GeoGebra Software

In recent years, the world has seen rapid growth in technology, including the introduction and design of educational software to support student learning. Up to now, the conventional instructional strategies employed in mathematics teaching in Ethiopia have not improved students' achievement and motivation; in fact, mathematical performance remains poor. The current national assessment confirms that the achievement of students in mathematics is below the expected standard. There is consensus that new pedagogical approaches are necessary to improve science and mathematics instruction in Ethiopia. This was the driving force behind the new Ethiopian educational road map, introduced in 2019 (Teferra et al., 2018). Although the rapid emergence of technological innovations holds great potential, Ethiopian schools are not ready to integrate technology into education. At the tertiary level, the new Ethiopian educational road map resulted in the integration of mathematical software such as MATLAB and Mathematica in the mathematics curriculum. These two packages are not freely available, however; the cost is thus restrictive. This forced me to explore the use of a free alternative at all educational levels, namely GeoGebra software. GeoGebra's mathematical applications are wide-ranging and enable the visualization and representation of some of the most complex mathematical concepts (Thambi & Eu, 2013).

The choice of GeoGebra coincided with my instructional goal of a teacher-student relationship according to the socio-cultural educational theory of Vygotsky (1978) and its later development in modern research termed known as "post-Vygotskian studies" (Daniels, 2001, p. 69). The emphasis in this theory is on the active disposition of the student in both student-teacher and student-student interaction - an aspect that GeoGebra enables. The achievement of students in mathematics can be increased by integrating technology usage in the classroom the gap between potential and actual development of students can be narrowed by the effective scaffolding of knowledge by the teacher.

Young et al. (1996) analyzed students' achievements about individual and institutional factors. At the individual level, factors that might affect students' achievements include their background, their attitudes towards science, the time they are exposed to instruction, their home environment and parental involvement. Similarly, Singh et al. (2002) argue that students' achievement in mathematics and science is affected by attitude, motivation and academic time, the greatest influence being the time spent on homework. Homework has the advantage that students grapple with ideas on their own but receive feedback from their teacher in the classroom–an effective means of assisting performance and facilitating learning in the zone of proximal development (Tharp, 1993). Where there is a lack of feedback from the teacher, student achievement is severely challenged. In my view, academic achievement refers to students' ability and skills and the marks they obtain in a subject. In this study, achievement refers to the effect of GeoGebra in calculus instruction, as reflected in students' pre- and post-intervention test scores.

A prerequisite for teaching and learning mathematics with the help of technology is a working knowledge of the software. Technology can simplify understanding; however, Galbraith and Haines (1998) argue that unfamiliar technology can raise difficulties, even if the tools are powerful. The availability of resources and computers, the awareness of stakeholders, teachers' pedagogical knowledge on integrating GeoGebra in their teaching, student-teacher ratios and the technological fluency of users are some of the requirements for delivering GeoGebra integrated mathematics education effectively in the classroom (Wassie & Zergaw, 2019). Students' prior experience and their computer skills are further determinants of the effectiveness of computer-assisted instruction (Mwei et al., 2012).

In a developing country such as Ethiopia, the availability of software at an institution may pose a challenge. Tay et al. (2012) identify institutional factors that might hinder the integration of technology in the classroom. These include the institutional context, the departmental ethos, the availability and accessibility of technology facilities, technological expertise in the department, teachers' technological skills and the opportunities for professional teacher development. Eng et al. (2011) found that rural students were less confident when using technology, while urban students' attitude towards mathematics learning through technology was significantly more positive.

Although institutions may face challenges when integrating technology in teaching and learning mathematics, and the process may be slow (Lavicza, 2010), Preiner (2008) reminds us that in this day and age many teachers and students have access to computers and software. The real difficulties are the integration of the software in the teaching and learning and teachers' ability (Ertmer, 2005; Gorder, 2008).

To sum up, once the challenges of employing technology in the mathematics classroom have been overcome, this mode of instruction has many advantages (Hew & Brush, 2007). The COVID-19 world has been forced to use technology, not only for teaching and learning but also in other sectors. Several scholars such as Alkhateeb and Al-Duwairi (2019), Arbain and Shukor (2015), Dogan and Icel (2011), Jelatu (2018), Rohaeti and Bernard (2018), Saha et al. (2010), Thambi and Eu (2013) believe that GeoGebra mathematical software encourages student achievements more than conventional teaching and traditional methods.

METHODS

Research Paradigm

The term paradigm was defined in the influential book entitled "The structure of scientific revolutions" by Thomas Kuhn in 1962 as a conceptual framework shared by a community of scientists that enables them to model problems and find solutions for community practitioners (Kuhn, 1996, p. 155). Guba and Lincoln (1994, p. 107) define a paradigm as "basic beliefs that deal with ultimate principles''; thus, a paradigm influences researchers when choosing the research questions and methods of study that will enable them to find solutions to their research questions (Morgan, 2007). Traditionally, there are three common research paradigms: positivist, interpretivism, and critical theory. For example, the interpretive/constructivist paradigm tries understanding and interpret what the subject is thinking about the concept (Kivunja & Kuyini, 2017, p. 33). All these paradigms (positivist, interpretivism, and critical theory) contain opposing ideas that have led to a "paradigm war" (Galvez et al., 2020, p. 613; Maarouf, 2019, p. 1) in terms of the three philosophical dimensions of ontology, epistemology, and methodology. As a result, the compromising paradigm known as the pragmatic paradigm has emerged (Teddlie & Tashakkori, 2009).

Understanding the most significant differences between the research paradigms and how they approach (ontology, epistemology, and methodology) these three philosophical dimensions helped the researcher to choose the best research paradigm for this study. It is thus to discuss these dimensions. Guba and Lincoln (1994) argue that the philosophical dimensions present three fundamental, interconnected questions:

The ontological question asks, "What are the form and the nature of reality?" Does "objective" reality exist "independent of the researcher"? The objective of this study is to investigate the use and effect on students' learning of mathematics of the GeoGebra mathematical software. By asking this question the researcher hoped to establish a reality somewhere between positivist (quantitative) and constructivist (qualitative) ways of knowing to examine the data in the study from both world views for triangulation purposes.

The epistemological question "What is the nature of the relationships between the knower and what can be known/participant?" is concerned with the acceptable knowledge in the study field (Saunders et al., 2009). Morgan (2007) defines epistemology as the nature of knowledge and the relationship between researcher and participants in the study. Drawing on ontology to establish a reality between quantitative and qualitative ideology, the researcher's task was to scaffold students in their learning of calculus with the help of GeoGebra mathematical software, using the hypothesized cycle model of teaching mathematics by GeoGebra. In the case of this scaffolding, and MKO is required. Thus, there is a relationship between the researcher and participants in terms of knowledge. In the epistemological philosophical dimension, reality is represented by objects that are considered to be real, such as computers, trucks, and machines (Saunders et al., 2009). Investigating the views of students on the use of GeoGebra before and after intervention.

Methodological questions include, how can the inquirer go about finding out whatever s/he beliefs can be known? The nature of the research question addressed in this study demanded the use of an explanatory methodology, which consisted of the investigation of the cause-and-effect relationships between the variables of the study such as teaching differential calculus with the help of GeoGebra (independent variables) and students' achievements and understanding (dependent variables) in the

Table 1. Summary of the philosophical dimension of the study and how this is related to the pragmatic research paradigm

Features and authors	Description
Objective of research	The study investigates the effect on students' learning of mathematics through GeoGebra mathematical software.
Ontology (nature of reality) (Morgan, 2007)	The researcher aims to find a way of knowing, understanding, mastering (subject matter & tools) by employing the sociocultural interactions (teacher with students) of Vygotsky's (1978) theory while students learn calculus by using GeoGebra mathematical software.
Epistemology (nature of knowledge & researcher/participant relationships) (Morgan, 2007)	The researcher, in this case, teacher (knower), is more knowledgeable than others (MKO) when teaching calculus with the help (scaffolded) of GeoGebra in experimental groups, and when teaching calculus using conventional methods. Thus, the study comprises the visible relationships between the knower (researcher) and the known (participants of the study, i.e., students) in terms of knowledge that reveals the nature of knowledge. In this case, researcher's task was to evaluate learning outcomes & make sense of constructed meanings of their new experience after gradually ending intervention.
Axiology (judgements about value (Saunders et al., 2009)	Values play an important role in interpreting results; the researcher adopted both objective (free from bias) and subjective (biased) points of view (Saunders et al., 2009).
Methods	Mixed method research (MMR)
Logic (Creswell, 2009)	Both deductive and inductive (as the study is MMR)
The possibility of causal linkage	There is a causal link in the study as is indicated in the objectives of the study.
Possibility of generalizability	The issue of sample size in the study

experimental group, and teaching calculus using conventional methods(independent variables) with their achievement(dependent variables) and hence, the study investigated the relationship between achievements and students' views on using GeoGebra which answered the methodological questions appeared in the study.

Considering these questions and the differences between research paradigms and how each related to the objective of this study, the researcher chose the pragmatic research paradigm for this study. The pragmatic paradigm is based on the researcher's plan to use a methodology that fits the problem to be investigated by the researcher (Teddlie & Tashakkori, 2009). In this case, the literature review revealed that mixed-method research (MMR) was appropriate when following the pragmatic research paradigm as it represents a compromise between the positivist and constructivist paradigms (Maarouf, 2019). Thus, a mixed-methods research approach was chosen for this study. Using only one research method (a qualitative or quantitative method) in a study is not always sufficient to obtain viable results, as a researcher strives or provide complete answers that meet the aim or purpose of the study (McMmillan & Schumacher, 2014; Offermann et al., 2009; Zainal, 2007). McMillan and Schumacher (2014) argue that a mixed-methods design is very important when the thinking of individuals or small groups is significantly different from that of the majority. **Table 1** shows summary of philosophical dimension of the study and how this is related to pragmatic research paradigm.

Research Design and Procedure

The researcher used a qualitative approach to determining students' perceptions of learning calculus through technology, in this case, GeoGebra. Quasi-experimental research uses non-randomized assignments of the group of the study that are categorized into experimental and control groups (Shadish & Luellen, 2005). Because of chose of this design, the study included 36 and 30 numbers of students in control and experimental groups. After some intervention through stage 1 through stage 7 were employed, the researcher administered questionnaires to these participants of the study.

Procedures

GeoGebra oriented lesson plan teaching in hypothesized cycle model

The developed GeoGebra oriented lesson plan with the use of ideas of TPACK frameworks were implemented by using hypothesized cycle model within this study. To get the required data of the study, the intervention lasts for four weeks by teaching students with the help of GeoGebra by using the stages and activities of the cycle model for experimental group and teaching the control group with traditional lecturer method. The stages and activities of developed cycle model is given in **Table 2**.

Data Sources

The closed-ended questionnaires and interviews for students and were the sources of data in this study. The items in questionnaires and interviews were based on the research objectives and research questions and the results of the pilot study were used to check the validity and reliability of the instruments. Questionnaires allow a researcher to obtain data to address the research questions in a study. Richards and Schmidt (2002, p. 438) argue that problems may arise when designing a questionnaire based on research questions; It is the task of the researcher to ensure that a questionnaire has validity, is clearly expressed and that it is scientifically reliable. Questionnaire items may be closed-ended or

Table 2. Stages of the cycle model

Stages	Name of the stages	Activities
1	Environment	Identification of area (environment) (such as laboratory class setting).
2	Individual behavior	Identification of individual areas (teacher professional development and student ability, perception). As the researcher was a teacher the MKO occurs, thus teaching and learning can take place. The pre-test was used to identify students' abilities.
3	State objectives	State objectives of teaching a lesson with GeoGebra (by using review literature).
4	Design	Design teaching materials (lesson plan that is compatible with GeoGebra).
5	Implementation	Implementation of a lesson plan in the classroom (start scaffolding student-student, teacher-student interaction).
6	Feedback	Get feedback from students. This could be in form of a post-test & interview.
7	Evaluation	Evaluation of whether the method had achieved what was intended. Comparison of abilities before and after.
8	Internalization & externalization	Disseminate & practice knowledge they obtained in the next stages of the cycle model.
9	Environment	Practicing the knowledge, they obtained within the environment by becoming MKO (such teachers, and other experts according to the types of intervention given).

Note. Adapted from Bedada and Machaba (2022)

open-ended. When using closed-ended questionnaires, data are quantified as they are numerical data, whereas in open-ended questionnaires the data are not numerical but in the form of text. In general, mathematics students from the mathematics department at Wachemo University were the sources of data for the study.

Sampling Method

In 2019, Ethiopia had 45 public universities. Of these, Addis Ababa University and Haromaya University are first-generation according to the categorization of Ethiopian universities. Universities are categorized according to the year they were built (from one generation to four generations ago). I chose Wachemo University, a third-generation university purposefully, specifically students studying in the Department of Mathematics. Wachemo University is situated in the Southern Nations, Nationalities and Peoples (SNNP) regional state of Ethiopia and is 230 km from the capital of the country, Addis Ababa.

One group of undergraduate students of mathematics made up the participants of the study. The numbers of these students depend on the capacity of the department and the researcher used a lottery or a simple random sampling method to select an experimental and control group for the study. This was achieved by identifying the section by coding (code number one indicating students who would be included in the study code number two indicating those who would be excluded from the study). In total, 30 and 36 freshman students learning mathematics were included in experimental and control groups. The researcher sampled students by writing the codes 1 or 2 on 60 to 72 pieces of paper. Placing these pieces of paper in a bowl, the researcher asked each student to take a piece of paper from the bowl. This method of including participants in a study is called the fishbowl draw or the lottery method.

Instruments

Interviews and questionnaires are data collection instruments that provide data for the researcher to analyze and interpret. Closed-ended questionnaires were administered to the experimental group after the intervention and students were interviewed. The focused group interview was chosen for this study because of the number of the individual chosen by the researcher. There were about five participants of individuals who participated in the interview thus simple to control the data. An interview is a specialized form of communication between people for a specific purpose associated with the research question of the study and whereas a focus group interview is a qualitative technique for data collection by discussions of the participants of the study on a given issue or topic (Dilshad & Latif, 2013).

Issues of Reliability and Validity

The closed-ended questionnaire was adopted and rearranged according to the context of the study following research by Bu et al. (2013), and the researcher computed its reliability by using a five-point Likert scale starting from strongly agree=1 to strongly disagree=5, with the scales between 1 and 5 coded as agree=4, neutral=3, and disagree=2. As the closed-ended questionnaire was intended for students, the questionnaire was distributed for students and the reliability of the questionnaire obtained from students who participated in the pilot study was computed and Cronbach's alpha was found to be 0.917 for students, implying that the questionnaires were reliable. The questionnaire comprised 14 closed-ended items and five interview questions to investigate the perceptions of students on the use of GeoGebra as an instructional tool. If the value of Cronbach's alpha of an item is equal to or greater than 0.5, then the item is considered acceptable, implying that it is reasonably reliable (Salvucci et al., 1997; Taber, 2018).

Table 3. Percentages and means of perceptions scales

Items	SD	DA	N	A	SA	Mean
Preferences in the classroom			Scales			
1: At the beginning, I did not like GeoGebra	11 (35.5%)	7 (22.6%)	5 (16.5%)	6 (19.4%)	1 (3.2%)	2.3 (3.7*)
2: I like GeoGebra because it is dynamic and free for everyone.	6 (19.4%)	4 (12.9%)	2 (6.5%)	7 (22.6%)	11 (35.5%)	3.433
3: Right now, I'm more open to learning using GeoGebra.	12 (38.7%)	7 (22.6%)	3 (9.7%)	5 (16.1%)	3 (9.7%)	3.6
7: I think working with GeoGebra is frustrating.	6 (19.4%)	9 (29.0%)	1 (3.2%)	5 (16.1%)	9 (29.0%)	3.0667 (2.933*)
8: I am comfortable with GeoGebra in learning calculus.	2 (6.5%)	-	2 (6.5%)	12 (38.7%)	14 (45.2%)	4.2
9: I do not want to use GeoGebra for my future study.	13 (41.9%)	7 (22.6%)	3 (9.7%)	2 (6.5%)	5 (16.5%)	2.3 (3.7*)
10: GeoGebra makes calculus more difficult for me.	12 (38.7%)	7 (22.6%)	3 (9.7%)	5 (16.1%)	3 (9.7%)	2.3333 (3.6667*)
12: Instructional material in learning calculus through GeoGebra is well organized.	2 (6.5%)	2 (6.6%)	1 (3.2%)	11 (35.5%)	14 (45.2%)	4.1000
15: I achieved better marks after I learned calculus through GeoGebra software.	3 (9.7%)	1 (3.2%)	2 (6.5%)	9 (29.0%)	15 (48.4%)	4.0667
Overall	2.16	1.42	0.72	2	2.424	3.7
Existence of software			Scales			
4: There is mathematical software for learning calculus in secondary school.	10 (32.3%)	2 (6.5%)	2 (6.5%)	9 (29.0%)	7 (22.6%)	3.033
5: There is no mathematical software for learning calculus.	3 (9.7%)	7 (22.6%)	3 (9.7%)	10 (32.3%)	7 (22.6%)	3.3667 (2.633*)
Overall	0.42	0.291	0.162	0.613	0.452	2.8
Scaffolding in the classroom			Scales			
6: I need a lot of help when doing new things by using technology like GeoGebra.	3 (9.7%)	3 (9.7%)	1 (9.7%)	9 (29.0%)	14 (45.2%)	3.9333
12: I get enough time to do the activity on my own in the laboratory classroom.	8 (25.8%)	7 (22.6%)	4 (12.9%)	2 (6.5%)	9 (29.0%)	2.900
13: I depended on others to do activity while program was running in classroom.	7 (22.6%)	8 (25.8%)	2 (12.9%)	4 (12.9%)	9 (29.0%)	3.000
14: I achieved better marks after I learned through GeoGebra mathematical software.	3 (9.7%)	1 (3.2%)	2 (6.5%)	9 (29.0%)	15 (48.4%)	4.0667
Overall	0.678	0.613	0.42	0.774	0.152	3.5

Data Analysis and Interpretation

Questionnaire items were grouped according to three core themes (perception towards the existence of the technology in the environment (the first step of the cycle model), perception towards scaffolding (the vertical and horizontal interaction step of the cycle model), and their preference for using technology/GeoGebra (individual perspectives step of the cycle model)). This was called the three-perception scale. Items such as 4.5 are grouped under 'perceptions towards technology', items 1, 2, 3, 7, 8, 9, 10, 11, and 14 are categorized as 'perceptions 'towards technology in learning, and items such as 6, 12, 13, and 14 are categorized as 'perception towards scaffolding' during the intervention. The results of the analysis of responses are provided in **Table 3**.

Students' perceptions were elicited by a questionnaire consisting of 14 items (nine items for perceptions towards GeoGebra, two items on the existence of the technology and four items on scaffolding by GeoGebra). The questionnaire was distributed to the experimental group only to determine their perceptions based on their experience of using the GeoGebra software. The results of the analysis of the responses to the questionnaire reflect students' perceptions towards GeoGebra for teaching in the classroom (with an overall mean of M=3.7) and perceptions of scaffolding activities (an overall mean of M=3.5) in the classroom. These were positive whereas perceptions towards the existence of technology for the mathematics classroom were negative (with an overall mean of M=2.8). It appeared that students were not familiar with the technology for teaching and learning calculus before the intervention. These students had never used GeoGebra before. This may be why they enjoyed using GeoGebra software for learning as it is a dynamic mathematical software (M=3.7). The study found that the items in the questionnaire that had the highest mean were those which showed that students were comfortable using GeoGebra for learning calculus (M=4.2), indicating that the software increased students' motivation, confidence, and achievement. The lowest mean was item 2.9, responses to which revealed that students did not think that working with GeoGebra was frustrating. Studies

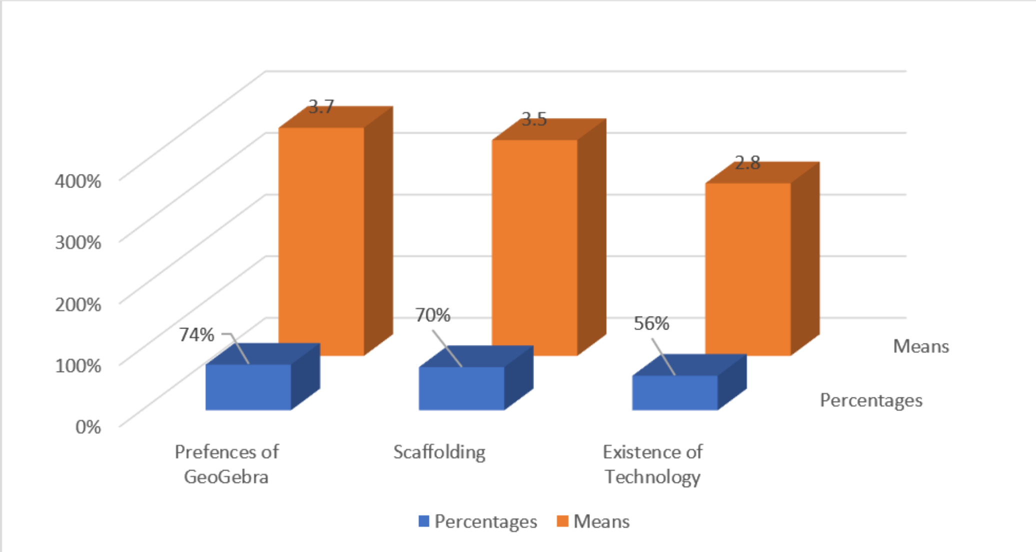

Figure 1. Percentages and means of three scales measuring student perceptions towards GeoGebra/technology

have found that technology in the classroom improves not only student performance and achievement but also student motivation (Harris et al., 2016). GeoGebra software can increase students' interest, confidence, and motivation in learning calculus. These findings correspond to those of a study by Arbain and Shukor (2015). The three-perception scale was developed by condensing the items in each category/theme; negative statements were reversed and recoded into positive statements (Sadeghiyeh et al., 2019).

Figure 1 was constructed by considering the overall mean scores of the three perception scales tabulated in **Table 3** out of 100%.

Figure 1 shows that 74% of students liked GeoGebra, implying positives attitudes towards the use of GeoGebra in the classroom; 70% of students were also interested in scaffolding activities [see Tharp's (1993) activities] that were included in the developed cycle model during the intervention. During the interviews, one student stated that he was "very interested in the program, and it should be expanded in [an] Ethiopia[n] context". He added that he was introduced to technology while at secondary school in a course on IT, but he indicated that there was no technology for teaching and learning calculus at elementary or secondary school. Another four students (56%) disagreed with this, saying that there was mathematical software available for learning calculus at secondary school. A further student (44%) ignored these ideas and can be accepted as neutral (mean approximately ~3).

Once the intervention had been completed, selected students from the experimental group were interviewed. Five willing students were selected purposively as this method is unique to qualitative research (Ranney et al., 2015). Directed content analysis, in this case, was recorded and enabled me to conduct data identification and categorization of the data into major themes (Reeves et al., 2015). The interviews were audio-recorded on a smartphone and transcribed verbatim. The transcribed students interviewed. This constituted the data for analysis. The transcripts were uploaded to the ATLAS.ti 9 computer software and coded. This also analyzed the data from the five students (Parker, 2021). The responses from the interviewed students were grouped for data analysis purposes and presented according to three themes (**Figure 2**).

Each of these themes related to students' perceptions towards the use of GeoGebra/technology in classroom learning as elicited by the closed-item questionnaire (**Table 3**) in line with the cycle model steps. The three themes connected to the research question were: perception of GeoGebra in terms of preference, perception of scaffolding in the classroom, and perception of the existence of technology in the classroom.

A revealing look at the narrative with the help of ATLAS.ti 9 computer software:

1. The initial steps consisted of an initial analysis of the material by listening to the recorded data to better understand it.
2. The document was uploaded as an audio file into ATLAS.ti 9 computer software.

Listening to the recorded audio in ATLAS.ti 9 computer software again and again to make text files. These (the narratives obtained from the interviews) were included in the ATLAS.ti 9 computer software.

1. Initiate the identification of the basic units of analysis (according to the themes) to provide ways to develop categories/themes to be analyzed by ATLAS.ti 9.
2. Pick keywords from each interview corresponding to all interview questions
3. Coding according to the similarities in text files

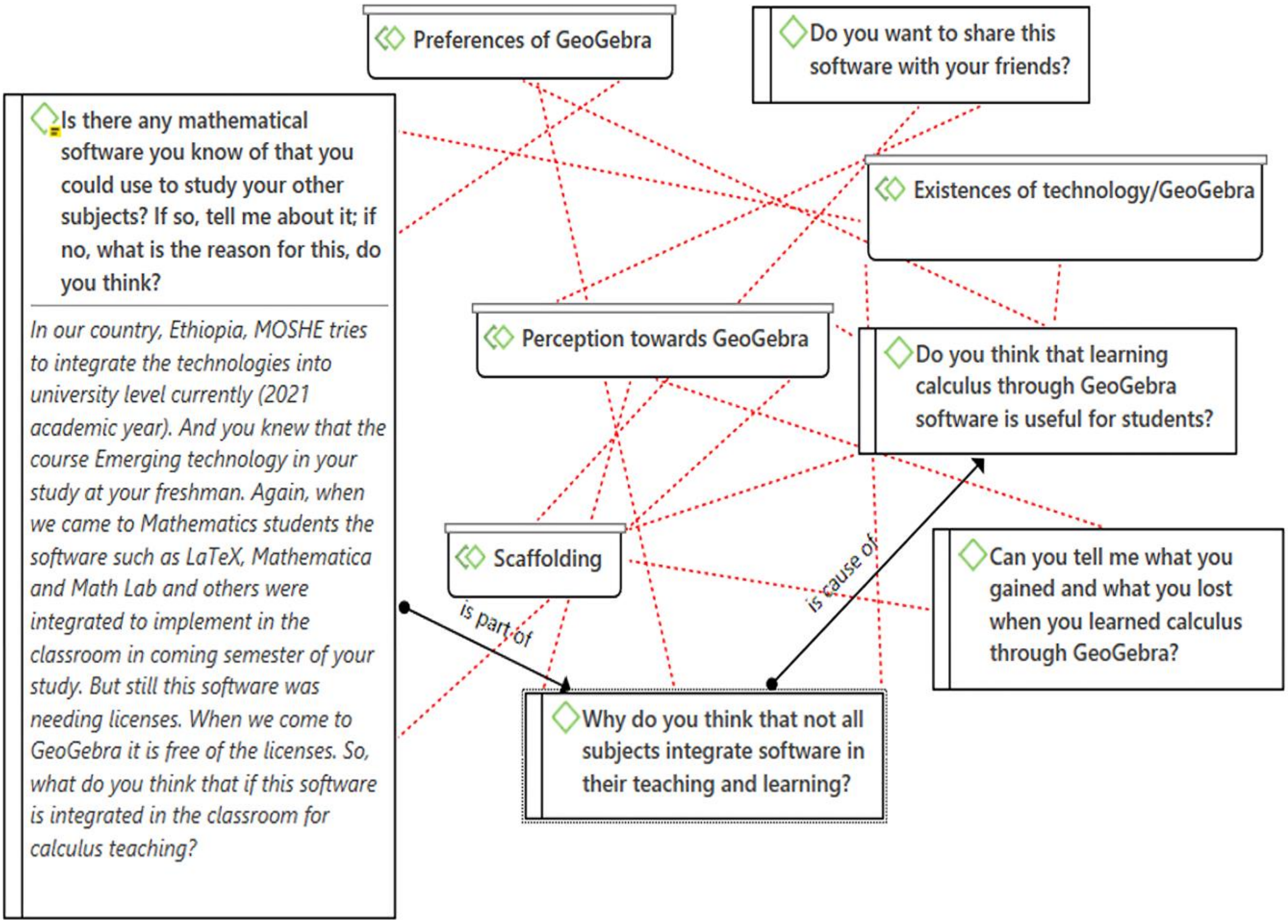

Figure 2. Interview themes

4. Finally, I used a graphics network for better analysis, and the narratives of all students were presented in boxes.

The views of students expressed during the interview were analyzed by grouping them according to three themes, as follows:

Theme 1 Preferences

The following figure shows the interaction between interviewers and interviewees as categorized according to the preference themes. Each interviewee interacted with all interview questions and recorded this on his or her smartphone. ATLAS.ti 9 allowed me to code the transcribed words and analyze the data.

Figure 3 indicates that students' responses demonstrated positive perceptions towards GeoGebra as all words were positive. The selection and decision of what technology to use and how to use it (implying preference) in the classroom increases the user positive perceptions towards integrating ICT/technology in the classroom (Thambi & Eu, 2013).

The responses to the interview questions (narratives of which are provided in each box) indicated that most students liked the GeoGebra oriented lessons using the computer (see the box in **Figure 3**): They think that it helped them to interact with each other to discuss and share their ideas. Generally, the worksheets developed by the applet helped them to learn the differential calculus topics. However, the students believed that they were helpless without the guidance of a teacher as they were new to the software despite their interaction with computers. In general, information gained from the interview responses when it had been coded by ATLAS.ti 9 can be summarized, as follows: even though students were new to the GeoGebra software, which can be regarded as a deficiency in computer-guided learning, they were nonetheless encouraged when using it to learn calculus in the classroom as it enhanced their independence and saved time. This suggests that embedding technology in the teaching and learning process is important, but it may be hindered by a lack of resources. The use of GeoGebra provides both teachers and students with a free tool, which is a new method of using technology to visualize calculus, helping students to interact with mathematical concepts individually (self-scaffolding) or in groups, in the classroom, at home or in any suitable place.

Lastly, during the interview, one student explained:

> "I found that GeoGebra gives a good impression of learning calculus. I feared Mathematics especially calculus for my study, but after I have installed the GeoGebra and try out calculus on my

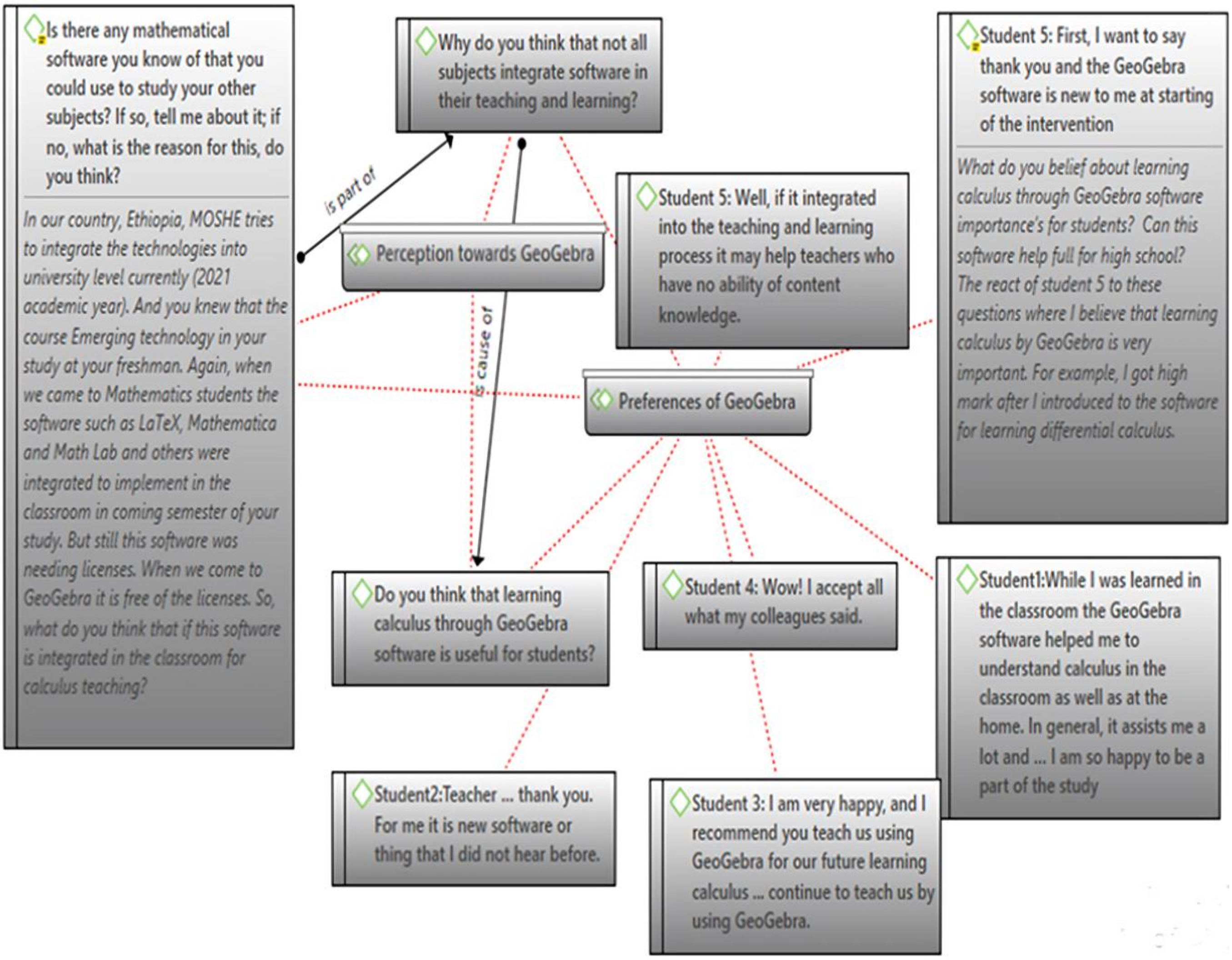

Figure 3. Students' responses during interviews on perception about preferences towards GeoGebra

> own at home, I am very impressed to use it for my future study."

The other four participants agreed with this. But one student wished to add something about the preference for GeoGebra in the classroom, saying,

> "I have a mobile, and I have a brother with the age of seven years old, but when I come back home from work, he immediately comes to me and took my mobile to play a game."

This implies that the seven-year-old knew how to manipulate the technology. I, therefore, recommend that instead of showing our children in Ethiopia how to play a game we should introduce them to mathematical software.

Theme 2 Scaffolding

As indicated in **Figure 4**, the scaffolding theme was covered by two of the interview questions presented to the five selected students. Their responses were recorded and coded and presented on the nodes of the figure as shown in **Figure 4**.

Figure 4 shows the responses as they were coded by ATLAS.ti 9. These indicate that most respondents said that a GeoGebra oriented classroom allowed students to communicate directly with the teacher and other students, and among themselves. This suggests that learning with software could trigger on-task interaction. These interactions increased students' interest in learning mathematics. They were also happy with the immediate feedback given to them while scaffolding was employed in the classroom.

Educational scaffolding is the dynamic intervention the zone of proximal development in a situation-based intervention by the teacher in the learning process of students creates a useful area (e.g., by posing questions, answering, getting feedback etc.) for exploring specific individual and group forms of support that can be captured in the interaction between teachers and students in the classroom environment (Seberová et al., 2020).

In summary, in this study students revealed positive perceptions towards scaffolding activities in the classroom. Students benefited from scaffolding in terms of immediate feedback and communication and

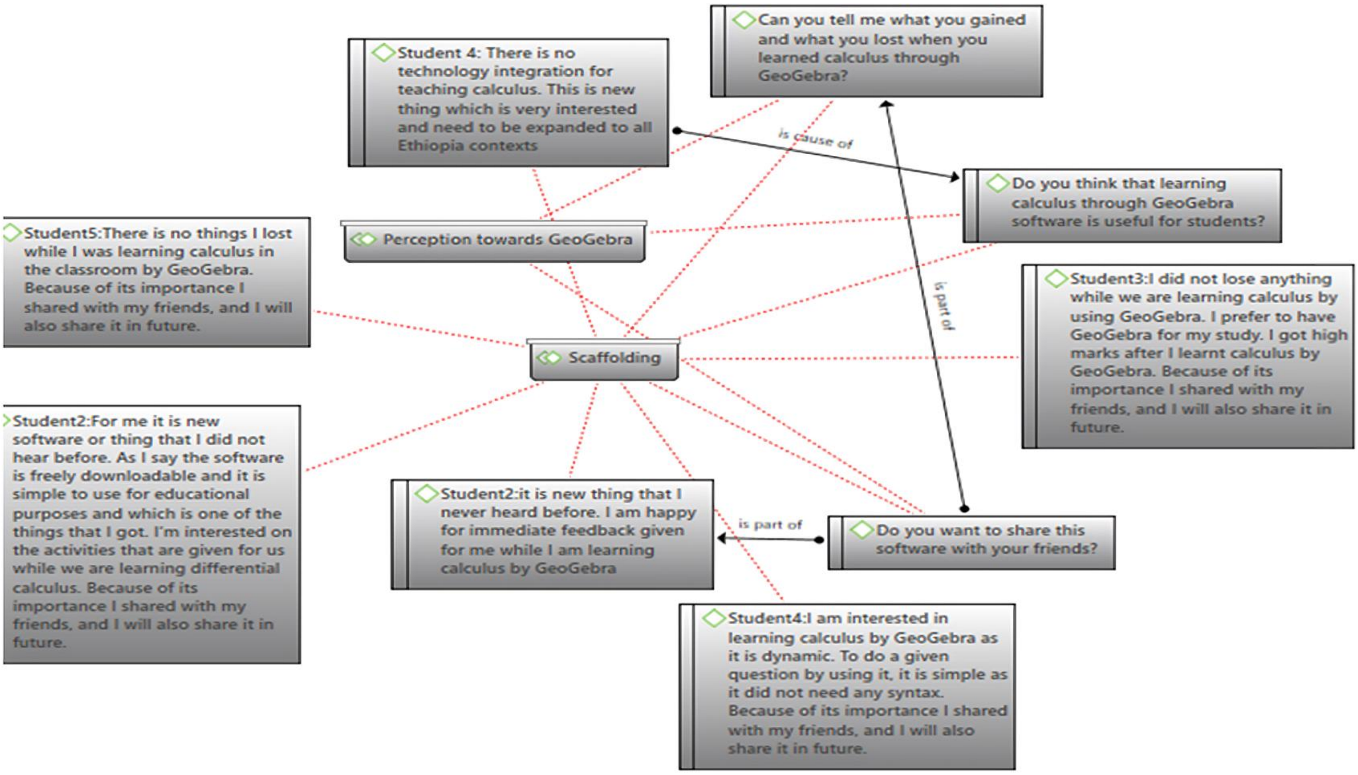

Figure 4. Students' responses during interviews on perception about scaffolding towards GeoGebra

improved their achievements in differential calculus. This allowed them to discover new mathematical knowledge (procedural and conceptual), supporting the findings of Željka and Trupčević (2017).

Theme 3 Existence

Two interview questions covered this theme:

1. Is there any mathematical software you know of to study your subjects? If so, tell me about some of them; if you do not know of any, why do you think this is so?
2. Why do you think that mathematical software is not integrated into all your subjects? The responses were recorded and uploaded into the ATLAS.ti 9, helping me to code the data as indicated in **Figure 5**.

During the interview, most students expressed the belief that there was no technology for teaching and learning in the classroom, specifically in the case of calculus at the elementary and university levels. Of the five students, only one was familiar with software known as Photomath; the others were new to technology. Some students said that the integration of technology was hindered by a lack of resources. These findings strengthen those from the perception scale in the quantitative phase of this study. The existence of computers/technology has a significant effect on the use of technology in the classroom (Nikolopoulou & Gialamas, 2015). One student said that MOSHE integrated one course known as emerging technology, and this had helped him to think about technology integration in the classroom. Another student recommended that the bodies concerned should consider the integration of technology in teaching and learning because he had benefited from the GeoGebra oriented classroom.

Most of the respondents stated that they were familiar with one course, known as IT, at secondary school but there was no software for learning calculus or other courses. They also stated that as the software used in the classroom in this study was freely accessed from the internet, educators should focus their attention on integrating it in the classroom to teach and learn calculus.

To sum up, in this phase of the study the results of the qualitative analysis showed a positive perception among students towards the GeoGebra oriented classroom. This is supported in **Figure 1**, which indicates that students' preferences for technology and scaffolding had a mean greater than neutral (n=3). This indicates positive perceptions toward GeoGebra in the classroom, in line with the findings of Arbain and Shukor (2015) and Dogan and Icel (2011). In general, the existence of technology, a preference for technology and scaffolding affects students' perceptions of the use of technology in the classroom. These findings support those of other researchers in the field (Nikolopoulou & Gialamas, 2015; Thambi & Eu, 2013; Željka & Trupčević, 2017).

FINDINGS OF THE STUDY

The research question in the study, what are students' experiences and perceptions towards using

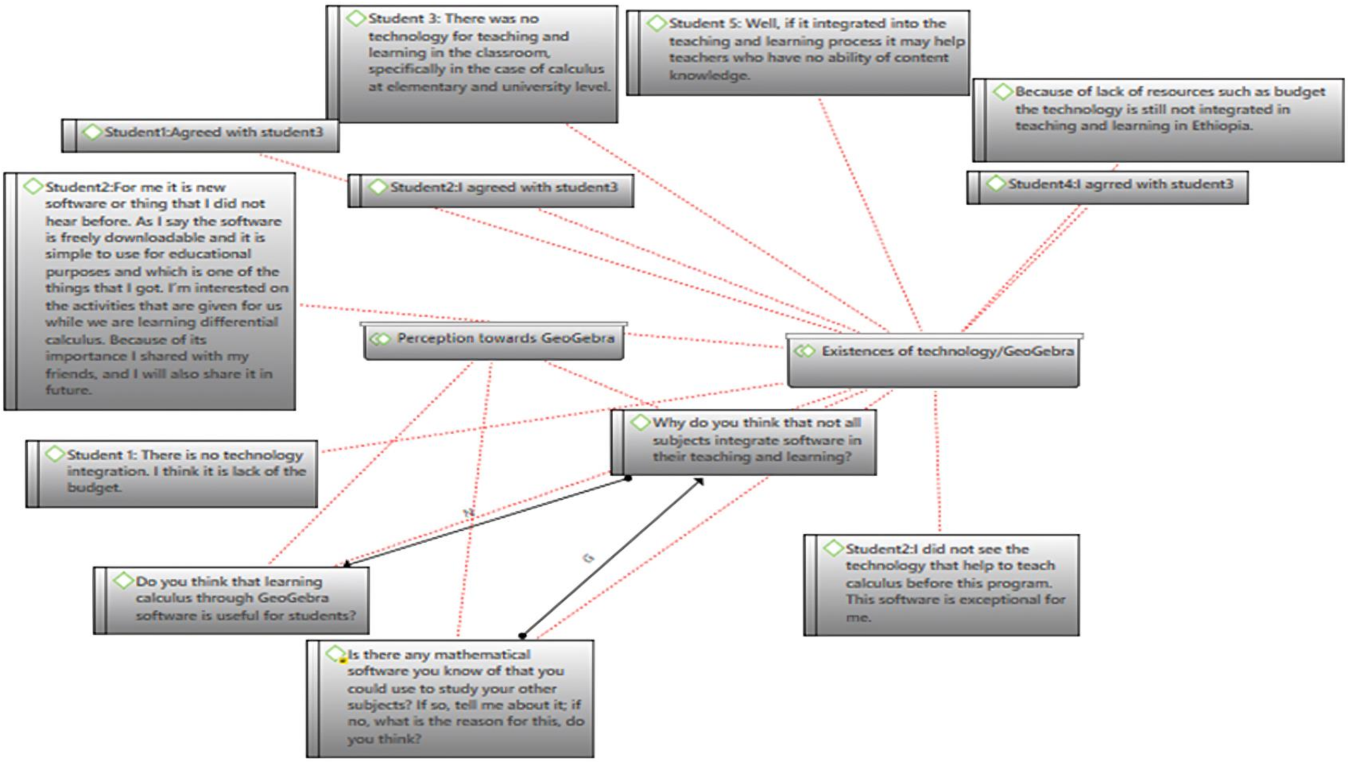

Figure 5. Student perceptions about the existence of technology

mathematical software (GeoGebra) in learning calculus concepts? was addressed by the questionnaire and interview. The items in the questionnaire and the questions asked in the interview were grouped according to three perception scales. These were the preference scale, the scaffolding scale, and the existence scale. Findings from these scales revealed that students had developed positive perceptions towards using the software GeoGebra in the classroom in terms of the preference scale, and towards the scaffolding activities included in the model during the intervention. Students were neutral on whether technology was integrated into elementary and secondary school mathematics teaching and learning, suggesting that they were neutral about the existence of technology or of using technology, particularly GeoGebra, at the school level for learning calculus (mean ~3) (Bretscher, 2014). These findings were consolidated in the interviews conducted with five students. ATLAS.ti 9 was used to categorize responses into three themes and to code these data for analysis purposes. The three themes connected to the research question were perceptions of GeoGebra in terms of preference, perceptions of scaffolding in the classroom, and perceptions of the existence of technology in the classroom, all found in the steps of the cycle model. In general, the existence of technology, a preference for technology, and scaffolding affected students' perception of the use of technology in the classroom, in line with the findings by Nikolopoulou and Gialamas (2015), Thambi and Eu (2013), and Željka and Trupčević (2017).

CONCLUSION

Learners in the 21st century need technological support in the learning process because of the advancements made in technology for teaching and learning. A GeoGebra-oriented classroom uses one of these technologies that can be implemented in the classroom. The study developed a new cycle model for the implementation of the technology of GeoGebra in the classroom according to nine steps. Based on the discussion and the findings of the study, the following conclusions can be made.

This study aimed to investigate the effect of GeoGebra software on students' learning differential calculus. It investigated students' perceptions towards the use of GeoGebra. One of the advantages came from the interactivity and supplementary materials. What students found important and attractive during the intervention was scaffolding when explaining the concepts, modelling, rearranging of fixed differential calculus questions on topics discussed in the classroom, immediate feedback, discussion forums, and supplementary materials, both online and offline, such as reference books and collections of previous worksheets. Thus, the role of the teacher lay in identifying both environment and student ability, designing, guiding, helping, assisting, facilitating, giving feedback, evaluating, and motivating students to use their learning in the classroom and environment after they had developed their understanding (internalization) for externalization. In this regard, Vygotskian theory holds that cognitive development can be described as a process of internalizing culturally transmitted knowledge (that can be held by scaffolded) in the cycle model (containing nine steps), in which the exposure to cultural models (cyclical model) stimulates a gradual internal process of knowledge growth in students learning differential calculus with the help of GeoGebra (Nezhnov et al., 2014; Vygotsky, 1978).

The perceptions of students were found to be positive towards the GeoGebra classroom-oriented approach, as respondents agreed that scaffolding activities offered learning opportunities that were better than those in traditional classrooms. Perception is a part of the process of using technology (Bruce & Hogan, 1998). The study found that 74% of students were satisfied with the preferences of the GeoGebra lesson-oriented course offered in the study while 70% were also interested in scaffolding activities and seeing Tharp's (1993) activities included in the developed model during interventions.

Student respondents felt that the GeoGebra classroom-oriented approach was an interactive, engaging, convenient, and more resourceful approach to logical thinking and discovery. In addition, GeoGebra's classroom-oriented approach allowed students to become familiar with computers and to build some essential skills for their studies. The developed cycle model was evaluated and brought positive changes to students' learning of differential calculus, in terms of both perception and scores. The study satisfied the principles of the fourth educational revolution which are that the teaching and learning process should be reshaped (Ally & Wark, 2020) and consistent with Common Core State Standards that do not recommend traditional teaching and learning approaches (Alabdulaziz et al., 2021). This study thus produced the cycle model for teaching and learning differential calculus using technology (Koehler & Mishra, 2009).

With the current rapid technological advancement, good quality education cannot be achieved without the integration of technology. That is why the Ministry of Education of Ethiopia has planned to implement an Ethiopian educational road map (Teferra et al., 2018). To this end, this road map (2019-2030) integrates technology such as MATHLAB, Latex, and Mathematica as one course named mathematical software for the mathematics department. However, not all these technologies are freely accessible from the internet. GeoGebra mathematical software is an open and freely available access software, however. This study thus recommends that the government integrates GeoGebra mathematical software in teaching differential calculus at the tertiary level with the help of cycle model. This study has shown the potential of a GeoGebra oriented classroom and the cycle model to benefit a developing country such as Ethiopia: the software is freely downloadable and can be installed on any computer or smartphone and it can be used offline. Developing countries could thus use this nine-step cyclical model of implementation of GeoGebra in their own context as educational software technology is still out of reach for many developing countries in this fourth education revolution era.

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Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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