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Research Article

The effectiveness of guided inquiry-based technology integration on pre-service mathematics teachers' understanding of plane geometry

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The study investigated the effects of a technology-integrated guided inquiry-based approach on pre-service mathematics teachers' conceptual understanding of geometry when compared to a guided inquiry approach and a traditional teacher-centered approach. A non-equivalent pretest-posttest control group quasi-experimental design was used. A three-stage sampling techniques was adopted. Two colleges were purposively selected and assigned to experimental and control groups through simple random sampling. A total of 116 pre-service primary mathematics teachers were assigned into three groups: experimental group1 (n = 48), experimental group2 (n = 38) and traditional group (n = 30). Pretest and posttest data were collected using a two-tiered test, and were analyzed with descriptive statistics, sample paired t-test and one-way ANOVA. Compared to the other two groups, pre-service mathematics teachers who received a technology-integrated guided inquiry-based approach showed a greater level of conceptual understanding. In accordance with the results, some recommendations were made for mathematics teacher educators.

Keywords: Plane Geometry; Technology integrated guided inquiry approach; Guided inquiry based approach; 5E lesson plan; Conceptual understanding

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1. Introduction

As a major area of mathematics, geometry often appears as a well-organized field of science with axioms, definitions, theorems, and proofs (Kurina & Siebeneicher, 2007). Geometry involves the study of shapes such as points, lines, planes, angles, triangles, quadrilaterals, circles, and solids, and the relationships between them. According to Battista (2007), geometry entails a complex set of interconnected concepts, ways of reasoning, and representational systems. In other words, geometric concepts have conceptual linkage, improve learners' logical and reasoning skills, and are also useful for problem-solving skills, deductive reasoning, and critical thinking (Mamali, 2015). In addition, geometry is essential for success in other mathematical disciplines (Atebe, 2008; French, 2004; NCTM, 2000). However, according to Fyfe et al. (2015), geometric concepts are the primary

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causes of difficulties in learning mathematics. Therefore, teacher educators should prioritize students' understanding of geometry.

Procedural and conceptual knowledge are considered necessary aspects of mathematical understanding (Eisenhart et al., 1993). According to Rittle-Johnson and Siegler (1998), procedural knowledge is the knowledge of sequences of steps or activities that can be used to solve mathematical problems. Star (2005) defined conceptual knowledge as knowledge of concepts or principles and procedural knowledge as knowledge of procedures. According to Chinnappan and Forresre (2014) and Star and Stylianides (2013), conceptual knowledge refers to a comprehensive understanding of concepts with complex relationships, principles, and definitions. In the same manner, Baroody et al. (2007) stated that conceptual knowledge is knowledge of concepts and principles, and their associations with each other. There has been a growing literature on conceptual knowledge in mathematics education in recent years (Star, 2005). As a result, the literature argues that conceptual understanding is significant in a variety of contexts. It is essential for more flexible problem-solving (Rittle-Johnson & Koedinger, 2005) and also important for learners to evaluate which procedure is appropriate in a given situation and to verify whether the solution is reasonable.

The foregoing indicates that learners who have conceptual understanding of geometry are able to describe the interconnections between geometric concepts, their definitions, and their rules, and explain why and how procedures must be followed for a logical and correct solution. According to the Ethiopian National Learning Assessment (ENLA), students perform below the intended national standards in geometry (MoE, 2015; 2017; 2020). Furthermore, ENLA (2015; 2017) observed that learners lack conceptual knowledge, application knowledge, and reasoning skills in geometry. Similarly, Kasa (2015) reveals that pre-service primary mathematics teachers' (PSMTs') conceptual understanding in geometry is inadequate. Researchers recommended use of learner-centered instructional approaches such as inquiry-based learning to construct conceptual understanding in learning mathematics and geometry (MOE, 2013). Additionally, incorporating technology into teaching mathematics and geometry promotes conceptual understanding among PSMTs (Atnafu et al., 2015; Gemechu et al., 2018; Mushipe & Ogbonnaya, 2019). The majority of teachers in Ethiopian higher education institutions and college of teacher education (CTEs) are still using traditional teacher-centered teaching methods (Ahmad, 2013; Bekele, 2012; MOE, 2015; Semela, 2014), which are less effective at conceptual understanding and internalizing concepts (Sebsibe & Feza, 2019). Rather than using traditional instructional methods, Sebsibe and Feza (2019) propose alternative teaching and learning methods involving educational technology.

Inquiry-based learning (IBL) is a learner-centered approach in which learners can solve problems, do experiments, and generate original ideas by connecting prior knowledge with novel ideas. It is a contrast to the traditional teacher-centered approach in that it emphasizes active learning through a constructivist model of instruction. Saunders-Stewart et al. (2012) also indicated that IBL enhances learners' achievement, knowledge application, thinking and problem-solving skills, and attitude towards learning more than the traditional approach. In the same manner, Abdi (2014), Maxwell et al. (2015), and Johnston (2014) also stated that the IBL method of instruction is more effective than the traditional methods. On the other hand, in activities associated with IBL (such as generating hypotheses, designing experiments, or interpreting data), learners need to be guided by their teachers in these activities. Different studies have shown that guided inquiry-based learning (GIBL) is more effective than unguided inquiry and traditional approaches (Lazonder & Harmsen, 2016; Minner et al., 2010). Alternatively, literature suggests that technology-supported learning methods enhance PSMTs' conceptual understanding in mathematics classes (Charles-Ogan, 2015; Idris, 2009). Integrating educational technology into the GIBL approach gives students new opportunities to examine abstract concepts. By integrating technology into guided inquiry-based learning (TGIBL), PSMTs can engage in higher levels of thinking and reduce cognitive load (Melese, 2014).

As a result, the curriculum framework for primary pre-service mathematics teacher education promotes the use of ICT and inquiry-based learning in the instruction of all mathematics courses (MOE, 2012; 2013). Studies have, however, revealed that such an instructional shift is yet to be practiced in colleges of teacher education in teaching mathematics and geometry remains an open question (MOE, 2015; 2020). In addition, the inquiry-based approach is extensively applied in the science classroom, but the practice of inquiry-based instruction has little emphasis in the mathematics classroom (Caswell & Labrie, 2017; Gardner, 2012).

1.1. Literature Review

Current literature concludes that technology tools necessary for educational transformation are not properly implemented during pre-service mathematics teacher education in Ethiopia. According to the policy on the standard of primary teacher education, it is necessary to incorporate instructional resources and ICT into the teaching and learning of mathematics content to the method of inquiry (MOE, 2013; 2015; 2020). Zamri and Zulnaidi (2017) highlighted that learners' conceptual and procedural understanding of function has been improved after the intervention of technology (GeoGebra) instruction. In the same manner, Blanchard et al. (2010) found that students in the GIBL approach outperformed than students in traditional classrooms in developing both content knowledge and reasoning skills. Using a quasi-experimental design consisting of a non-equivalent post-test only control group, Saha et al. (2010) examined the impact of GeoGebra on students' achievement in coordinate geometry and revealed the effectiviness of technology on student achievement. Similarly, Gemechu et al. (2018) conducted a mixed research approach to compare the effects of MATLAB assisted traditional lecture method, MATLAB supported collaborative method, collaborative method, and traditional lecture method on conceptual understanding of functions among Walkite University Engineering students. The study conluded that students taught with MATLAB technology-assisted learning along with a collaborative method understand function concepts better than other groups.

Other researchers also found that students who were taught using IBL and technology outperformed those who were taught using traditional methods, and suggested technology could be used to support GIBL by increasing motivation and interest toward learning (Goh et al., 2013; Hannafin et al., 2007). Abdi (2014) investigated the impact of using a 5E lesson plan in a learning environment that is designed around inquiry-based instruction. Based on the ANCOVA analysis, students who were taught science using the 5E lesson plan outperformed those who were taught using traditional methods. Türkman (2009) also compared inquiry-based instruction enhanced by educational technology with teacher-directed traditional instruction and discovered the inquiry approach enhanced by educational technology performed better. Additionally, Almeqdadi (2000) demonstrated a significant difference between those who used dynamic geometric software versus those who used the traditional approach to understand geometrical concepts. According to the statistical results, using GSP to teach geometrical concepts improved students' conceptual understanding. A similar study found that technology assisted instruction (GeoGebra) was beneficial for learning and teaching challenging concepts in geometry (Andraphanova, 2015). Therefore, technology can facilitate student-centered instruction, cooperative learning, and improved teacher-student interaction.

This research was initiated to investigate the effect of TGIBL and GIBL approaches on PSMTs' conceptual understanding of plane geometry. By demonstrating effective learning environments and methodologies, the study has significant implications for preservice mathematics teacher education. For the purpose of this study, a technology-integrated 5E lesson plan was used. Therefore, the following hypotheses were proposed:

- There is no significant mean difference between the mean scores of conceptual understanding of geometry across all groups.
- There is no significant mean difference between the pre-test and post-test mean scores of conceptual understanding of geometry for each group.

2. Method

2.1 Research Design

A quasi-experimental with a non-equivalent control group design was adopted into this study. This design is chosen when random assignment of participants is not possible (Creswell & Plano-Clark, 2011). The researchers employed a control group to make comparisons with the experimental groups, which were not randomly assigned (Cohen et al., 2007; Creswell, 2012). A quasi-experimental design was conducted to explore the effects of using a GIBL and TGIBL approach on PSMTs' conceptual understanding of plane geometry. The design is as summarized in Table 1.

Table 1
Research Design Layout

Group		*Intervention*	
Experimental Group1 (EG1)	Pretest	TGIBL	Posttest
Experimental Group2 (EG2)	Pretest	GIBL	Posttest
Comparison Group (CG)	Pretest	TRAD	Posttest

Note. TGIBL: technology integrated guided inquiry approach, GIBL: Guided Inquiry approach, TRAD: Traditional

Table 1 shows the two experimental groups and the comparison group of PSMT. Samples in the three groups were pre-tested using the Geometry Conceptual Understanding Test (GCUT) before interventions. After the interventions, all the three groups were assessed with a post-test that contained the same types of questions

2.2 Participants and Sampling procedure

The study participants were all second-year PSMTs from CTEs in Ethiopia's Oromiya regional state (Department of Mathematics) who registered for Math-111 (Plane Geometry) during the 2019/2020 academic year. A total of 116 PSTs, aged 19 to 26 years, took part in the study.

This study used a three-stage sampling technique. To begin with, purposive sampling was used to select two CTEs (Dambi Dollo CTE and Shambu CTE) based on equivalency in computer laboratories, academic and ICT facilities, candidate enrolment, and similarity in demography. The purposive sampling approach, according to Fraenkel and Wallen (2009), is used when the researchers believe that useful data can be obtained under certain conditions (Fraenkel & Wallen, 2009). Then, the colleges were assigned to experimental and comparison using a simple random sampling method. In this case, Dambi Dollo CTE was sampled as an intervention college while Shambu CTE was sampled as a comparison college.

In the final stage of the sampling method, the intact classes from Dambi Dollo CTE were assigned to TGIBL and GIBL groups using with simple random sampling method. The first experimental group (EG1) (# TGIBL = 48) used a technology-guided inquiry approach, the second experimental group (EG2) (# GIBL = 38) used a guided inquiry approach, and the comparison group (Comp) (# Comp = 30) used a traditional lecture method.

2.3 Instrument for Data Collection

The conceptual understanding of plane geometry was measured through a two-tiered test (pre-test and post-test). The plane geometry conceptual understanding test (GCUT) was prepared to determine the PSMTs' conceptual understanding of plane geometry concepts. GCUT is a diagnostic two-tiered test (TTT). First, there is the content response (first tier), followed by a set of multiple-choice questions and an additional blank space for explanation (second tier). (See Appendix A)

Additionally, a table of specifications with content areas was prepared. We used the specification table to ensure a fair distribution of propositional knowledge from the plane geometry (See Table 2).

Table 2
Table of specification

Topics of plane geometry	*Number of items*
Triangles	10
Quadrilaterals	8
Polygons	3
Circles	9

Various approaches are used in the existing literature to evaluate the TTT item. As an example, Treagust et al. (2007) define a two-tier question as correct if both tiers are answered correctly. Furthermore, Tarakci et al. (1999) stated that if PSMTs answer correctly in both tiers, they are generally considered to be well versed in geometric concepts. PSMTs were assessed on their descriptive or factual knowledge of the geometry concepts to be assessed using the first tier, and their reasoning in the second tier was validated using the second tier. To diagnose students' understanding, Lin (2004) devised a TTT. Using such a test to assess students' understandings and identify alternative conceptions proved to be a feasible approach. Table 3 shows the evaluation criteria of the TTT used for measuring the conceptual understanding of plane geometry among PSMTs. For instance, Figure 1 shows the evaluation of a PSMT response scored as 1.

Table 3
Criteria for the evaluation of TTT questions in plane geometry concept

First tier	*Second Tier*	*Score*
True response	True reason	1
True response	False reason	0
True response	No reason	0
False response	No reason	0
False response	False reason	0

The criteria listed in Table 3 were used to rate each item, and the total scores that the PSMTs obtained from the test were computed using these scores. The test can have a maximum score of 30, and a minimum score of 0.

2.4 Validity and Reliability

2.4.1 Validity

The validity of a research instrument is defined by Saunders et al. (2009) as a method of measuring what the instrument was designed to measure. Two of the most widely used aspects of validity are content validity and face validity. As noted by Kothari (2004), content validity occurs when the instrument has covered the area fairly and adequately (Cohen et al., 2007). Accordingly, subject professionals from mathematics education and curriculum and instruction were advised to check the instruments' content/face validity.

The GCUT items were reviewed by a PhD candidate and mathematics teachers' educators from CTEs for consistency, clarity, and errors in the answer key based on benchmark points such as the adequacy of sample questions and whether the research objectives aligned with the syllabus. Prior to the pilot study, some of the items were revised using feedback and comments from experts. The table of specifications for content validity is depicted in Table 2.

2.4.2 Reliability

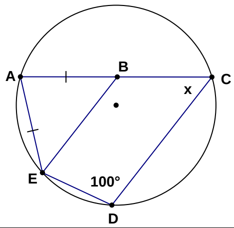
Another method of evaluating instrument stability and participant consistency is reliability. The methods of test-retest, equivalent form, and internal consistency exist to provide reliability (Fraenkel & Wallen, 2009). According to Ary et al. (2010), the internal consistency reliability of a test or scale is measured by Cronbach's coefficient alpha and Kuder-Richardson coefficient alpha, respectively.

Figure 1

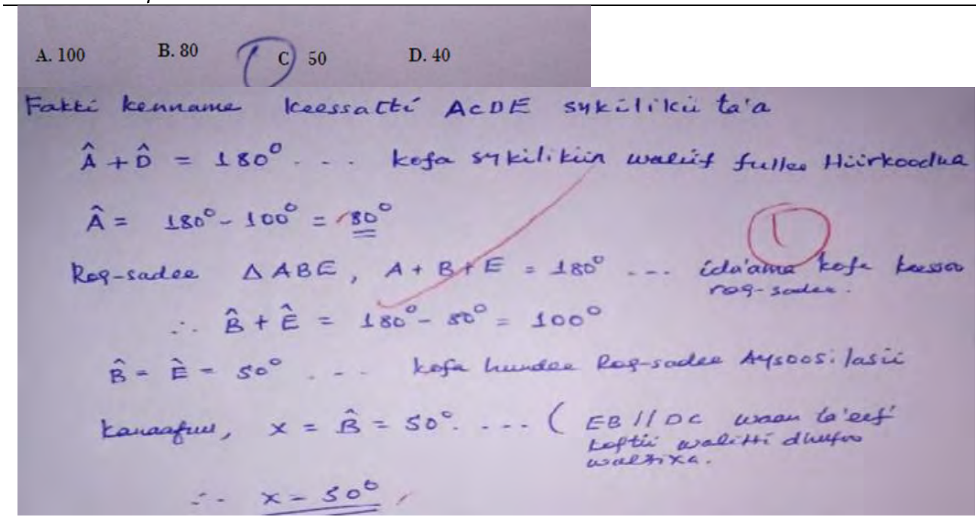
Evaluation of a PSMT response to the 19th question in the test

Question 19

In the figure, ACDE is a cyclic quadrilateral with $EB \parallel DC$ and $AB = AE$.
a)Find the value of x.
b) Jusify your response step by step.



Student response



Tier 1

Tier 2

In the figure, ACDE is cyclic quadrilateral, then
$\hat{A} + \widehat{D} = 180^0$ (Since opposite angle of cyclic are supplementary)
$\hat{A} = 180^0 - 100^0 = 80^0$ (Since angle D is given a measure of 100^0)
$\hat{A} = 80^0$
It is given that, ΔABE is an isosceles triangle since ($\overline{AB} \equiv \overline{AE}$)
Then, $\hat{A} + \hat{B} + \hat{C} = 180^0$ (Since the sum of interior angle a triangle is 180^0)
$\hat{A} + \hat{B} + \hat{C} = 180^0$
$\hat{B} + \hat{C} = 180^0 - 80^0 = 100^0$
$2\hat{B} = 100^0$ ….. ($\hat{B} \equiv \hat{C}$) (Since the base angle of an isosceles triangle is congruent)
$\hat{B} = 50^0$
$\hat{B} = x = 50^0$ (Since $EB \parallel DC$ the corresponding angle are congruent)
Therefore, $x = 50^0$

A pilot study administered the GCUT to 60 PSMTs selected from Fitche CTE who had completed the plane geometry course. Based on Kuder-Richardson's 20 formula (KR20), the internal reliability coefficient was determined to be 0.76. KR20 indicates that the value is within acceptable ranges. Accordingly, the test items of the current study were found to be valid and reliable. The mean difficulty level of 0.43 and discrimination index of .47 are also within acceptable ranges (Boopathiraj & Challamani, 2013). The final version of the test items was delivered as pre- and post-tests to measure PSMTs conceptual understanding of plane geometry concepts before and after intervention, after passing all these procedures.

2.5 Piloting Study and Intervention Procedure

2.5.1 Piloting the instructional models

Pilot study of plane geometry tasks and activities created using TGIBL and GIBL models of instructional approach was evaluated by professionals from curriculum and instruction and a PhD candidate in mathematics education, followed by PSMTs who are not participants in Fitche CTE research. Participant observations and discussions with mathematics teacher educators and PSMTs were used in the pilot study. Several statements of activity and tasks were modified based on feedback gained from pilot observation, participants, and experts. Several activities were designed for use in either GSP or GeoGebra or both.

A 5E lesson plan for teaching plane geometry was used to design and implement content and tasks under the GIBL and TGIBL approaches. An introduction is usually followed by some practical examples or a strong guided investigation, with each step clearly explained and interim questions formulated. Each task was followed by a discussion, and then examples and conclusions. The integrated technology 5E teaching lesson plan as TGIBL and GIBL consists of five phases: Engage, explore, explain, elaborate, and evaluate. For a sample 5E lesson plan, please see Appendix B. (A detailed description of 5E model can be found in Bybee, et al., 2006).

2.5.2 Procedure of interventions

In an interview conducted prior to the experimentation, it was revealed that all of the instructors were adept at using computers, but was unfamiliar with Dynamic Geometry Software (DGS) as an instructional tool. Intervention and comparison groups recruited teacher educators with Master's degrees in mathematics education and equivalent teaching experience in CTEs. Training was provided to teacher educators in the experimental groups on implementing treatment, using the TGIBL and GIBL, interacting in inquiry settings, applying computer assisted learning packages (GSP, Geogebra) in guided inquiry-based learning settings, and guiding the use of inquiry learning strategies. Training lasted for six days and included an overview of the TGIBL and GIBL, their development, and how to use 5E lesson plans.

Two research assistants assisted the researcher in administering a pre-test to PSMTs before interventions began. Afterwards, four hours of intervention per week were provided for a semester (12 weeks). In the experimental groups, PSMTs were randomly divided into groups of four to five, based on the classroom teachers' comments and their academic abilities. Following are the specific practices for each group:

Experimental Group I (EG1): Guided inquiry-based technology integration. The TGIBL approach was used to teach plane geometry concepts to PSMTs. PSMTs were divided into four-to-five member heterogeneous groups in this strategy. In this approach, the researcher examined whether the groups were able to learn plane geometry activities such as triangles, quadrilaterals, polygons, and circles. In this study, the tasks involved visualizing geometric shapes, manipulating and dragging them, and analyzing and making conjectures using technology (GSP, GeoGebra, YouTube video). The 5E instructional sequence was used (see Appendix B).

Experimental Group II (EG2): Guided inquiry-based learning approach. GIBL, in which collaborative and hands-on activities are employed, was used to teach plane geometry concepts to PSMTs. PSMTs were guided in solving these problems since inquiry requires learners to discover new knowledge by applying prior knowledge. During this procedure, the teacher educator asked PSMTs to think and discuss, which is the first requirement of inquiry, such as: how can you be sure it is correct? Can you explain what you have done? It is intended to prepare PSMTs to make explanations based on evidence and to evaluate those explanations. To elicit explanations and evidence, PSMTs conduct hands-on experiments and activities. To help PSMTs solve problems, conjecture, and experiment, they are given activities and geometric tasks. Using concrete materials as manipulatives, students were introduced to geometric properties and concepts through cutting, folding, pasting, connecting, and modeling activities.

Comparison Group (Comp): Traditional teacher-centered method. For the comparison group, a lecture method was used. Teacher educators followed the usual trend of traditional lectures used in most higher education institutions in Ethiopia for their instructional tasks. In this trend, PSMTs take notes and passively listen to lectures. At the beginning of the class, the teacher educator provides notes, worksheets, and a midterm test at the end of each chapter. In addition to presenting the content, the math fundamentals, and geometric formulas to be copied from the board, the teacher educator also worked on some sample examples and wrote some questions for the PSMT to answer. The teacher educator did not use any manipulative, real-life examples, or technology in this case.

After interventions, GCUT was administered as a post-test to assess the conceptual understanding of different groups in learning plane geometry. PSMTs answered the GCUT independently at pre-test and post-test. The same geometry content and module (plane geometry (Math-111)) were used by all groups. The researchers provided feedback at the end of classroom activities on the process of interventions for further improvement.

2.6 Data Analysis

It was checked whether the data was parametric or non-parametric before analysis. The data in this case fulfills the assumption of parametric tests. The use of parametric tests is performed when a population follows a particular distribution with a set of parameters, such as the normal distribution. Research can use a t-test or an ANOVA to compare the means of two groups on the dependent variable when comparing the means of two groups (Ntumi, 2021; Snow, 2014). We used the ANOVA test in this study because we had a continuous dependent variable, a nominal variable (independent variable/instructional method), three experimental groups/factors, and three different participant groups. Based on the data obtained from the pre- and post-test of the GCUT, we conducted an analysis of variance (ANOVA), Scheffes post-hoc analyses, and paired t-test statistics with a 0.05 alpha level.

3. Results

The findings are presented in accordance with the research hypothesis. A one-way ANOVA requires that the data meet the assumptions. First, the data must meet the following criteria: normal distribution, homogeneity of variance, randomly selected sample unit, independent scores on the dependent variable, and data measured at least once (Field, 2009). Table 3 below presents descriptive statistics related to pretest and posttest scores.

Table 4
Descriptive statistics on pretest and posttest of GCUT across groups

	Group	*N*	*Mean*	*SD*	*SE*
Pre-test GCU	EG1	48	18.20	6.44	.93
	EG2	38	18.00	4.18	.68
	Comp	30	18.07	4.69	.86
Post-test GCU	EG1	48	27.39	6.69	.97
	EG2	38	23.79	4.63	.75
	Comp	30	21.13	6.89	1.26

To test normality, skewness and kurtosis values were used, while Levene's test was used to test homogeneity. Pre- and post-test homogeneity of variance for the GCUT between the groups is shown in Table 5.

Table 5
The Skewness and Kurtosis and Levene's test on pre-test and post-test GCU among groups PSMTs

				Levene's test	
Variables	*Group*	*Skewness*	*Kurtosis*	*F*	*p*
Pre-GCU	EG1	−.364	−.394	1.938	.149
	EG2	.142	−.813		
	Comp	−1.066	1.876		
Post-GCU	EG1	−.540	−.472	1.701	.187
	EG2	.050	−1.326		
	Comp	−.464	−.167		

Note. Pre-GCU: Pretest conceptual understanding, Post-GCU: Posttest conceptual understanding

George and Mallery (2003) suggest that the Skewness and Kurtosis values should range from −2 to +2 for the normal distribution of the data. Based on Table 4, skewness and kurtosis values ranged between −2 and 2, indicating a tenable normality distribution (Mallery, 2003). The Levene's test for pre-test pre-GCU is (F (2, 113) = 1.938, p =.149), whereas the Levene's test for post-test post-GCU is (F (2, 113) = 1.701, p =.187), indicating that the homogeneity of variance was attained for the dependent variable (Field, 2009; Pallant, 2010). Prior to investigating potential differences between groups, it is important to determine their equivalence at the pretest level. The ANOVA test for pre-test geometric conceptual understanding is presented in Table 6.

Table 6
One-way ANOVA test comparing all groups on pre-test score among the groups

Variable		*SS*	*df*	*MS*	*F*	*p*
Pre-test GCU	Between Groups	3.682	2	1.841	.074	.929
	Within Groups	2807.033	113	24.841		
	Total	2810.716	115			

From Table 6, the ANOVA value (F (2, 113) = 0.017, p = 0.983) indicates that there was no significant difference in pretest score. This indicates the groups were nearly equivalent before the intervention.

H0[1]: *There are no significant differences in conceptual understanding of geometry of pre-service mathematics teachers taught plane geometry using technology integrated guided inquiry based learning (TGIBL), guided inquiry based learning (GIBL) and traditional teacher-centered teaching method.*

To determine whether there were significant differences in the post-test mean scores of the TGIBL, GIBL, and comparison groups, an ANOVA test was performed. Table 7 shows the result of the analysis.

Table 7
ANOVA results of post-test of conceptual understanding of geometry among groups

		SS	*df*	*MS*	*F*	*p*	*Eta squared*
Post-test GCU	Between Groups	755.105	2	377.55	9.98	.000	.150
	Within Groups	4275.032	113	37.83			
	Total	5030.138	115				

According to Table 7, a statistically significant difference was found between the groups of PSMTs on conceptual understanding of geometry (F (2, 113) = 9.98, p < .05). As a result, the null hypothesis (H0 [1]) was rejected. The eta squared (η^2 = .15) indicates the strong effect size of treatment on dependent variable (Cohen, 1988).

Since the ANOVA test for the post-test conceptual understanding of geometry shows a statistically significant mean difference between groups, Scheffe's test was used as a post hoc-test to determine the differences. Table 7 shows the result of post-hoc analysis.

Table 8
Schaffe's post-hoc multiple comparison analysis of groups means scores

Dependent Variable	*(I) group*	*(J) group*	*Mean Difference (I-J)*	*SE*	*p*
	EG1	EG2	3.59*	1.34	.02
Post-test GCU		Comp	6.24*	1.43	.00
	EG2	Comp	2.66	1.50	.24

Note. *the mean difference is significant at the 0.05 level.

The result in Table 8 indicates that there was no significant difference in the post-test mean scores of PSMTs exposed to GIBL (M = 23.79) and those exposed to traditional teacher-centered approach (M = 21.13). It also indicates a significant difference in the post-test mean scores of PSMTs exposed to TGIBL (M = 27.39) and traditional teacher-centered approach (M = 21.13). A significant difference was also established in the post-test mean scores of PSMTs exposed to the TGIBL approach (M = 27.39) and GIBL approach (M = 23.79). EG1 performed better than EG2 and Comp, with a mean gain of 3.59 and 6.24, respectively. This demonstrates that using technology in a guided-inquiry approach improved conceptual understanding of geometry more than a guided-inquiry approach and a traditional teacher-centered approach.

$H0_{[2]}$: *There is no significant mean difference between pre-test and post-test mean score of conceptual understanding of geometry in each group.*

In Table 9, pre-test and post-test results using a paired t-test are presented for each group of PSMTs. In this case, further analysis was conducted to determine the extent of improvement in PSMTs before and after the interventions.

Table 9
Paired Sample t-test pre- and post-test results on conceptual understanding of geometry

Group	Variables	Paired differences			t	df	p	Cohen's d
		MD	SD	SEM				
EG1	PostCU – PreCU	9.79167	6.59128	.95137	10.292	47	.000	1.59
EG2	PostCU – PreCU	5.78947	4.50320	.73052	7.925	37	.000	1.33
COMP	PostCU – PreCU	3.36667	5.58621	1.01990	3.301	29	.003	0.57

Note. PreCU: Pre-test conceptual understanding, PostCU: Post-test conceptual understanding

As shown in Table 9 the mean difference between the comparison group's post- and pre-test scores was 3.36 at $t(29) = 3.301$, $p = .003$, indicating that the difference between pre-test and post-test scores is significant. The effect size, Cohen's $d = 0.57$, which is a medium effect (Cohen, 1988). Similarly, the mean difference between the EG2 posttest and pretest is 5.78 at $t\ (29) = 7.925$, $p < .001$, indicating that the post-test performs better than the pre-test. The effect size, Cohen's $d = 1.33$, shows a very large effect. In the same manner, the mean difference between the posttest and pretest of EG1 is 9.79 at ($t\ (47) = 10.292$, $p < 0.001$). This shows the mean difference between the pre- and posttest scores is in favor of the post-test. The effect size, Cohen's $d = 1.59$, shows a very large effect. As a result, PSMTs exposed to technology integrated guided inquiry performed better than PSMTs exposed to guided inquiry and traditional inquiry, and PSMTs exposed to guided inquiry performed better than PSMTs exposed to traditional inquiry.

4. Discussion and Conclusion

In this study, we examined the effectiveness of technology-integrated guided inquiry-based learning, guided inquiry-based learning, and traditional teacher-centered approaches in improving PSMTs' conceptual understanding of plane geometry. A significant mean difference was found between the GIBL, TGIBL, and traditional teacher-centered methods used to teach geometry to PSMTs regarding conceptual understanding of geometry. The eta squared (η^2) value also showed that the intervention contributed 15% to the analysis of variance for the posttest mean scores. In other words, the intervention made a difference between the groups.

To identify where significant differences in post-test scores occurred between the groups of PSMTs, Scheffe's test was used for post-hoc analysis. Consequently, PSMTs exposed to TGIBL outperformed those exposed to GIBL and traditional instruction methods. Those results are also consistent with those reported by Gambari and Yusuf (2016), Gemechu et al. (2018), Zamri and Zulnaidi (2017), Saha et al. (2010), and Goh et al. (2013) found that students who received computer-assisted instruction performed better than those who received traditional instruction. A similar study by Türkman (2009) found that inquiry-based instruction is most effective when aided by educational technology.

The results concur with those of Unal and Cakir (2016) and Yimer (2020), who found that students taught mathematics using technology-assisted instruction performed better than those taught using a constructivist approach. In addition, Nopasari et al. (2020) found that teaching mathematics through the 5E learning cycle helped learners understand mathematics. Because technology integrated inquiry provides an opportunity to learn abstract mathematics concepts, it helps students understand them better. Furthermore, learner-centered approaches in educational technology (GSP, GeoGebra, etc.) aid in visualizing abstract concepts.

According to another result, however, conceptual understanding of geometry did not significantly differ between groups exposed to GIBL and those exposed to traditional teacher-centered instruction. This result is inconsistent with results of the study (Artigue & Blomhoej, 2013; Maxwell et al., 2015; Wares, 2016) stated that students learned through guided inquiry outperformed traditional approach. In both experimental groups (EG1 and EG2) and the comparison group, there is a significant mean difference between pre-test and post-test results, with Cohen effect sizes of $d = 1.59$, $d = 1.33$, and $d = .57$. Technology-integrated guided inquiry and guided inquiry approaches show a high effect size, while the comparison group shows a medium effect size. PSMTs exposed to TGIBL also show a higher mean gain than PSMTs exposed to GIBL or traditional approaches. In other words, technology-integrated guided inquiry is more effective than both guided inquiry and traditional instruction methods. Toquero et al. (2021) suggests that technology can provide learner-centered online learning environments which may result in supporting the student learning. Kado (2022) also concluded that technology enhanced learning environments with the help of coding activities have a potential to support student achievement. Although students may face some challenges in online learning (Ullah et al., 2021), educators can and should overcome these and prepare effective technology supported learning environments.

Based on the above results, it can be concluded that technology integrated guided inquiry based learning produced more positive outcomes on PSMTs' conceptual understanding in geometry concepts. This study shows that guided inquiry-based learning can be used to teach geometric concepts more effectively within a technology-integrated setting. With technology-integrated guided inquiry, geometry content can be delivered in an active, stimulating, and peer-to-peer collaborative way. Therefore, it is a more effective method to teach geometry in a teacher education college.

5. Recommendations

Based on the results, the following recommendations were made:

- In the teaching of plane geometry, mathematics teacher educators should encourage the use of technology-integrated guided inquiry instructional strategies to promote active learning, discovery learning, and learning by doing.
- In order to increase successful teaching and learning, the Ethiopian College of Teacher Education program should be upgraded to train teachers who are capable of using innovative approaches (e.g., technology-integrated instructional techniques).
- This study contradicts previous research that shows a significant difference between guided inquiry-based learning and traditional approaches in favor of guided inquiry. Therefore, further empirical research is needed in Ethiopian teacher education colleges.

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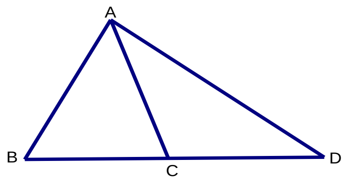
Appendix A. Sample geometry test items

The following sample test measures pre-service mathematics teachers' conceptual understanding of plane geometry using two-tiered multiple choice questions.

Question 8.

a) In the figure $m(A\hat{B}C)$ $(B\hat{A}C)$ is given, then which of the following is true?

A. AD > BD
B. AD = BD
C. AD < BD
D. AD > AC + DC



b) Jusify your response step by step.

Question 16.

a) If the lengths of the two altitudes of a parallelogram are 2 cm and 4 cm and its perimeter is 24 cm, then the sides in cm of the parallelogram are respectively:

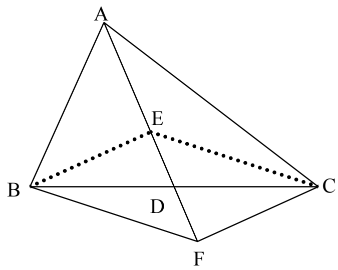
A. 2cm, 10cm
B. 4cm, 8cm
C. 3cm, 9cm
D. 5cm, 6cm

b) Jusify your response by drawing a parallelogram.

Question 22.

a) In figure, E is the intersection of the medians of ΔABC, $\overline{BF} \parallel \overline{EC}$ and $\overline{FC} \parallel \overline{BE}$. If AD = 3cm, then AF is equal to ___

A. 4cm
B. 2cm
C. 6cm
D. can't be determined



b) Jusify your response step by step.

Appendix B. A lesson plan prepared in terms of 5E model

Table: TGIBI and GIBL Sample Lesson Plan - The triangle properties Interior and Exterior Angles of Triangles
This strategy focused and attention must be given to the following:

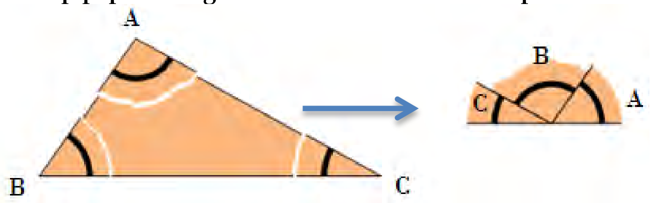
- Encourage group activities
- Use concrete instructional aids/hands-on activities
- Organize activity based instruction
- Allow students interactions through independent work
- Encourage discussion.

This lesson plan includes the objectives, prerequisites, and exclusions of the lesson teaching students how to complete geometric proofs using the angle sum of a triangle and find interior and exterior angles of triangles.

Prior knowledge: PSMTs should recognize
- o Alternate interior, corresponding angles of parallel lines are equal in measure.
- o A straight angle is 180^0 in measure.
- o Facts about supplementary, adjacent and vertical angles.
- o Types of triangle (Acute, obtuse, right, equilateral, isosceles, scalene etc.)

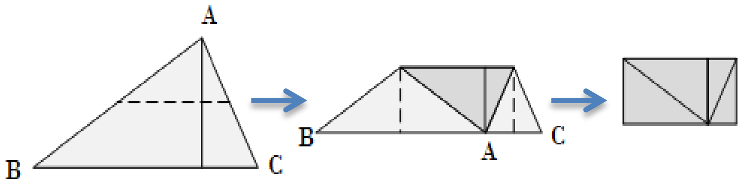
Method: Charts, cut materials, module, investigating with GSP, YouTube video.

Objective: At the end of lesson PSMTs will
- Determine the sum of the interior angles of a triangle.
- Solve missing angles problems involving the interior angles of a triangle.

Phase	Activities Examples
Engagement • Teacher will capture PSMTs' interest. • Access PSMTs prior knowledge.	PSMTs are given some materials on triangle. Guide students to recall their previous knowledge about angle, triangle, alternate, corresponding angles. Have each PSMTs draw triangles. Distinctly differentiate triangle.
Exploration **(Pair-investigation)** • Describe what hands-on/minds-on activities PSMTs will be doing. • List "big idea" conceptual questions the teacher will use to encourage and/or focus PSMTs exploration	• Have the PSMTs measure the three angles of the triangle. • In groups of 4 or 5 PSMTs will explore sketches of different triangles, use an applet to construct triangles, and then explain their reasoning triangles angle measure. **Cut-up paper triangles and have students line up the vertex angles to create a straight angle.**  Use the three angles and line them up on a line back to back. (Angle to angle) Have the students discuss what happens. They should discover that the three angles line up to form a straight line. What do angles A, B, and C forms together? What do you conclude? i.e <A + <B + <C =____________

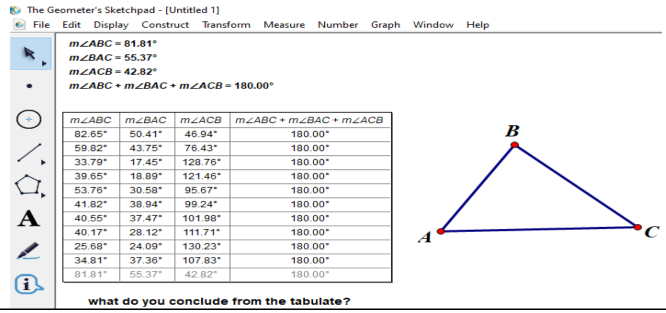
Appendix B continued

Fold the other three vertices so that all three meet at the same point.



What do angles A, B, and C forms together? What do you conclude?
i.e <A + <B + <C =______________

- **Geometric Sketchpad Applet** (Teacher prepare GSP files for investigation)



Explanation (pair-discussion)

- After completing the exploration in groups, the PSMTs will return to a whole-group setting and present their groups' answers.
- Teacher will probe PSMTs for responses about their conclusions.
- Technology may be used to further clarify the concept and relevant vocabulary should be defined to fix misconceptions.

Elaboration (whole class- discussion) Consolidation

- Teachers give new scenarios or problems and provide directive questions
- After the activity, come together as a whole class to compare discoveries. Clear up any misconceptions. Check that the properties always work. Make sure each team tested all possible cases.
- A tutorial on how to show the triangle sum of 180 degrees on sketchpad is located at math-g8-m2-topic-c-lesson-13-teacher.pdf
- www.edugains.ca/resourcesMath/VideoLibrary/Video/TechnologicalSupports/gsp/mp4/SumOfAllAngles_Video2.mp4
- The Geometer's Sketchpad™ (GSP) (edugains.ca)

Have students use the proof blocks to prove the angles of a triangle sum to 180 degrees.
Therefore, the sum of the three angles a, b, and c is 180°. Hence, we have proved the triangle sum theorem.
The sum of all interior angles of a triangle is equal to 180°.
Triangle sum theorem holds for all types of triangles

Evaluation

- PSMTs discuss and apply the concepts covered with self and teachers.
- Practice activities are given.

Exercise: 1) The three angles of a triangle are 35°, 67°, and 100°. Is the statement true?
2) Using the angle sum theorem, calculate the value of x for a triangle whose angles are x°, (x + 20) °, and (2x + 40)°.