

Effect of Van Hiele group guided-discovery instructional approach on student engagement in learning plane geometry

Alemayehu Anbess Gebremeskel^{1,2*}, Mulugeta Atnafu Ayele³, Adem Mohammed Ahmed²

¹Hawassa College of Teacher Education, Hawassa, Ethiopia

²Bahir Dar University, Bahir Dar, Ethiopia

³Addis Ababa University, Addis Ababa, Ethiopia

*Correspondence: ligabbaa@gmail.com

Received: Mar 17, 2025 | Revised: Nov 12, 2025 | Accepted: Nov 13, 2025 | Published Online: Apr 12, 2026

Abstract

Learning geometry involves using visual manipulatives, mathematical formulas, and verbal explanations to foster critical thinking, deductive reasoning, and problem-solving skills, thereby ensuring understanding of mathematical concepts. Despite this relevance, secondary school students' limited knowledge in plane geometry, especially in concepts such as polygons and circles, creates an epistemological barrier that hinders their engagement with more advanced geometric ideas. Thus, this study investigates the effectiveness of the Van Hiele Group Guided-Discovery Instructional Approach (VHGGDIA) on student engagement in learning plane geometry, employing a mixed-methods research approach with a Convergent Parallel design. It uses a quasi-experimental, non-equivalent control-group pre-posttest design. Two comparable secondary schools from a total of 11 schools were purposively selected and randomly assigned to the experimental and control groups. Honesty, independence, perseverance, attention, interaction, and collaboration — each of which demonstrates dedication, kindness, and teamwork — impact student engagement. The analysis incorporated data from interviews, observations, and a Likert scale questionnaire. Quantitative data analysis used descriptive statistics, independent and paired-samples tests, and ANCOVA, whereas qualitative data were assessed thematically. The study found that students using the VHGGDIA showed greater engagement in plane geometry than those taught via traditional methods. Further, the study concludes that VHGGDIA significantly enhances secondary school students' engagement in this subject.

Keywords:

Engagement to learn, Plane geometry, Self-confidence, Van Hiele group guided instructional model

How to Cite:

Gebremeskel, A. A., Ayele, M. A., & Ahmed, A. M. (2026). Effect of Van Hiele group guided-discovery instructional approach on student engagement in learning plane geometry. *Infinity Journal*, 15(2), 391-420. <https://doi.org/10.22460/infinity.v15i2.p391-420>

This is an open access article under the CC BY-SA license.



1. INTRODUCTION

Mathematics is a crucial subject in schools that promotes logical reasoning, critical thinking, and problem-solving skills (Adler & Sfard, 2016; Belay et al., 2016). Further,

learning mathematical concepts is crucial for enhancing student potential and encouraging active participation in new ideas (Mentari & Syarifuddin, 2020). Geometry is one branch of mathematics that improves students' ability to reason, visualize abstract concepts, and solve practical problems (Hidayati et al., 2019). Geometry instruction enhances students' visual imagination, deductive reasoning, and logical reasoning skills, facilitating their understanding of geometric concepts and relationships (NCTM, 2000). It is also an important field to understand advanced topics in science, technology, engineering, physics, statistics, and geographic information systems and contribute to aesthetic appreciation in art, architecture, and music, as it facilitates the examination of the physical world (NCTM, 2000; Zhang, 2017). Moreover, due to its close relation to humane experience, geometry serves as a valuable tool for students to overcome everyday challenges (Jablonski & Ludwig, 2023; Singh & Kumar, 2022). The National Council of Teachers of Mathematics underscores the importance of visual representation and hands-on activities to boost engagement and spatial understanding (NCTM, 2000). Besides, mathematical proficiency relies on conceptual understanding, procedural fluency, strategic competence, adaptable thinking, and a positive attitude, all of which are essential for problem-solving. Geometry lessons significantly enhance these ability by fostering the visual interpretation of abstract concepts (Hidayati et al., 2019). However, research shows that students have disengaged in learning geometry (Belay et al., 2016).

Student engagement in the school curriculum involves understanding of their mental abilities, emotional connections to the subject, and active participation inside and outside classroom activities to achieve successful outcomes (Trowler, 2010). Students who acknowledge their abilities are more likely to engage emotionally in classroom activities, participate effectively, and apply their knowledge to solve problems. Besides, Moenikia and Zahed-Babelan (2010) recognize that student engagement is essential for learning and personal development since it increases their interest in learning, fosters a sense of belonging, and offers various growing chances for gaining evidences and skills. Different researchers classify student engagement as cognitive, behavioral, affective, and social components, stressing the interconnectedness of these elements for a comprehensive understanding of the subject (Fredricks et al., 2004; Wang et al., 2016).

Cognitive engagement refers to the mental effort students invest in mastering content, employing effective strategies, and actively participating (Fredricks et al., 2004; Wang et al., 2016). A cognitively engaged learner actively invests in their learning, aiming to exceed basic requirements and demonstrating thoughtfulness, strategy, and a willingness to tackle complex ideas and difficult skills. This component enables the assessment of student participation, stressing task effort, persistence through challenges, intentional learning, positive emotions, deep information processing, and collective activities.

Behavioral engagement refers positive conduct in the classroom instruction and persistence in school work including participation in extracurricular activities (Fredricks et al., 2004; Wang et al., 2016). Working hard in learning activities and being active in extracurricular activities greatly inspires students in acquiring successful knowledge through different knowledge sources (Latif et al., 2025). In this dimension, student encompasses learning behaviors such as maintaining focus, exerting effort, adhering to rules, and positively engaging in classroom tasks with teachers and peers. Behavioral contribution in learning can

be improved by aligning the learning situation with learning goals. This connection aids students in their mental effort in class, as those adhering to behavioral norms and avoiding negative behaviors become active participants.

Affective engagement encompasses students' emotional responses and attitudes toward classroom learning (Fredricks et al., 2004; Wang et al., 2016). Students' feelings about learning activities can range from boredom to interest, which significantly reflects their intrinsic motivation. This motivation is essential for a deep understanding of classroom learning. Thus, students with high affective engagement are intrinsically motivated to learn and have a strong attachment to their schools. The last element of engagement for this study was social engagement, which is defined as meaningful relationships with teachers and students throughout classroom teaching (Fredricks et al., 2016; Jansen, 2020). Social interaction promotes collaboration that identifies shared ideas from the surroundings, which raises student involvement in class instruction.

Context, consistent expectations, and support from school and family significantly influence student engagement (Mentari & Syarifuddin, 2020). The school environment significantly influences the teaching and learning process. Adequate classroom facilities, including sufficient space, enable student participation. Teachers must monitor student involvement, considering their expectations for activities. Students are more engaged in class when there is regular communication with their families and administrative assistance in providing the required resources (Shernoff et al., 2016; Shernoff et al., 2017). Skilling et al. (2016) found that students' success histories impact their engagement levels. Ethiopia's education policy aims to develop cognitive skills, emphasizing strong connections with teachers and peers (Ministry of Education, 2021).

However, many students fear mathematics due to its perceived abstract nature, leading to frustration and disengagement (Nyman, 2020; Tanujaya et al., 2017). In a survey conducted by Shernoff and his colleagues, students expressed no interest in mathematics and often ranked it as the most challenging high school subject (Shernoff et al., 2016; Shernoff et al., 2017). In Ethiopia, the Japan International Cooperation Agency (JICA) case study also highlights challenges in Ethiopia's science and mathematics education, noticing students' lack of engagement and motivation (Belay et al., 2016). The lack of student engagement and motivation in classroom instruction negatively affects their achievement in the classroom (Skilling et al., 2016). Research argued this issue as there is a positive correlation between student engagement and academic achievement (Lei et al., 2018). Student disengagement in classroom instruction results in poor academic achievement (Abla & Fraumeni, 2019). Thus, failure to address this engagement issue will have a significant negative influence on students' academic performance and society at large.

The essential elements influencing students' engagement in geometry learning include inadequate prior knowledge, unsuitable teaching strategies, and the failure to connect classroom contents to real-world applications (Dorra, 2021; Fabiyi, 2017). The teacher-focused teaching approach faces challenges in promoting student active participation in the classroom (Emanet & Kezer, 2021; Garner, 2015). The absence of initial knowledge results in anxiety and diminished confidence, hindering active participation in classroom instruction (Brezavšček et al., 2020). Students become less engaged when they perceive the contents as

irrelevant due to the mismatch between classroom instruction and actual-life situations. Thus, effective teaching approaches are essential for enhancing student engagement and academic achievement in the classroom. Additionally, effective teachers are intentional, create a supportive learning environment, and set high expectations for student learning (Goodwin & Hubbell, 2013). One of the primary challenges in enhancing student engagement is facilitating active participation through suitable teaching methods.

Numerous studies on the topic have demonstrated that students' achievement is greatly impacted by their engagement in mathematical learning. The significance of engagement in mathematics instruction is emphasized by these findings (Alrajeh & Shindel, 2020; Maamin et al., 2021). Alrajeh and Shindel (2020) assert that instructional support has the greatest impact on student engagement. This study indicates that an effective teacher's instructional approach significantly boosts students' active participation in the classroom, even if it does not identify specific teaching strategies that contribute to this effect. An intervention study in a real mathematics classroom is necessary to close this gap. Maamin et al. (2021) also highlights the need for a supportive environment that fosters students' engagement in mathematics, while also addressing the challenges of balancing cognitive, affective, and behavioral engagement in math learning. This survey highlights the significance of effective classroom instruction, yet it does not recommend specific teaching strategies to improve student engagement. Furthermore, the researchers have not found any empirical studies that support students' engagement in learning plane geometry in the current study area. Thus, the researchers intended to evaluate effective teaching strategies that promote active student engagement in learning plane geometry.

Because it promotes a student-centered approach that fosters critical thinking and enables students to solve issues via exploration and experimentation, the guided discovery learning technique is essential for learning mathematics by inviting students to engage, particularly in plane geometry (Balm, 2009; Bruner, 1961). Additionally, the Van Hiele instructional model emphasizes geometric thinking stages and teaching phases to enhance students' concept understanding (van Hiele, 1986). This instructional method emphasized cognitive engagement, as it required students to exert mental effort to fully grasp the concepts. These methods are deemed effective in teaching geometry (Siregar et al., 2020; Subagis, 2021; Suratno et al., 2019; Ugwoke et al., 2020). In addition, cooperative learning promotes student engagement by fostering teamwork (Remillard, 2015; Zakaria, 2010). However, the researchers have not seen any evidence demonstrating that combining these three teaching strategies effectively increases students' engagement in studying plane geometry. Thus, the purpose of this study is to determine how successfully the van Hiele group-guided discovery instructional approach (VNGGDIA), which was developed by combining all these three teaching strategies, raises student engagement in plane geometry. The Van Hiele model enhances cognitive engagement, whereas guided discovery learning promotes behavioral engagement and social interaction via cooperative learning.

This study investigates how VHGGDIA influences the engagement of tenth-grade students in learning plane geometry, which precisely answers the following research question, RQ1 : Is there a significant mean gain difference between the Experimental and control groups before and after the intervention?

RQ2 : Is there a significant mean difference between pre- and post-test results in a group?

RQ3 : How do the VHGGDIA improve student engagement in learning plane geometry?

2. METHOD

To investigate the effectiveness of the VHGGDIA on student engagement in plane geometry, the study employed a mixed-research approach with a concurrent triangulation (Convergent Parallel Design) strategy (Creswell & Creswell, 2018). A quasi-experimental, non-equivalent control group pre-posttest design was used due to the inability to randomly assign students in intact classrooms (White & Sabarwal, 2014).

2.1. Population and Sampling Techniques

Tenth-grade students (2022/2023) from government secondary schools in Hawassa, Ethiopia, participated in the study. The study involved a purposeful selection of three secondary schools from eleven secondary schools found in the city, based on criteria such as infrastructure, stakeholder willingness, and teacher qualifications to ensure equivalent groups. A pilot study was carried out at one school with sixty-three students, followed by the main study in the other two schools. For the intervention and control groups, the remaining two selected schools were randomly assigned, and one teacher from each was chosen based on their willingness, experience, qualifications, and personal traits. A section of fifty-six students from the groups taught by the selected teacher was randomly chosen for each school.

2.2. Data Collection Instruments

The study modified a 5-point Likert-scale engagement questionnaire proposed by two authors to align with specific concepts in plane geometry (Fredricks et al., 2004; Wang et al., 2016). Supervisors (mathematics education instructors) and an experienced college psychology instructor evaluated the revised engagement rating scale questionnaire, along with the interview and observation questions. The tools were first created in English and subsequently translated into the students' native language to enhance interaction. Two English language experts performed independent translations of the same document, with a third expert verifying the translations' consistency. Tenth-grade students completed the same Likert-scale engagement questionnaire before and after the intervention, rating their responses from 1 (strongly disagree) to 5 (strongly agree), with reversed scoring for negative statements. Classroom observations were conducted using a modified checklist from Subban and Round (2015). Additionally, the study interviewed the two participating teachers to gather insights on the intervention, guided by questions related to engagement ratings and observations questionnaires.

2.3. Validity and Reliability of the Instruments

Through pilot study assessed the reliability of the engagement rating scale, leading to revisions of the observation and interview questions. The reliability of the engagement rating scale was verified using Cronbach's alpha in both the pilot and main studies.

Table 1. Reliability coefficient of engagement rating scale

Questionnaires	Components	Reliability Coefficients			
		N	Pilot study	Pre-test	Post-test
Engagement		40	.911	.804	.885
Components of engagement	Cognitive	10	.763	.738	.757
	Behavioral	10	.777	.751	.720
	Affective	10	.700	.739	.769
	Social	10	.801	.704	.757

Table 1 shows the engagement rating scale's internal consistency reliability coefficient for the pilot study (0.911), pre-test (0.804), and post-test (0.885). The findings showed that every evaluation stage had appropriate reliability coefficients, each of which were larger than 0.700.

2.4. Factor Analysis

Using a Pearson bivariate correlation, the study ensured no correlation values exceeded 0.8. An exploratory factor analysis was performed on 40 engagement questions based on pre-intervention data. The principal component factoring technique with varimax rotation was utilized, suppressing item-loading coefficients below 0.4 and retaining factors with eigenvalues greater than 1 (Kaiser, 1974). Initially, there were eleven components, but the analysis was restructured by eliminating items with communality below 0.3 and cross-loading items, resulting in four factors. After twelve iterations, a stable solution emerged with 22 items and four factors (see **Table 2**).

Table 2. The items loading on each factor

Factors	Items	EV	RCEF	RCAI	ACEF	ACAF
Factor 1	11, 14, 16, 17, 18	4.072	.793		.589	
Factor 2	23, 24, 27, 28, 29, 30	3.233	.710		.681	
Factor 3	3, 4, 5, 6, 7	2.131	.732	.714	.523	.629
Factor 4	31, 32, 33, 38, 39, 40	1.728	.712		.698	

Note:

EV = Eigenvalue; RCEF = Reliability coefficient of each factor; RCAI = Reliability coefficient of all items; ACEF = Average communality of each factor; and ACAF = average communality of all factors.

On the 22 items, the KMO statistic was 0.741 (very good), and the correlation matrix determinant was 0.001 (greater than 0.00001), confirming the suitability for factor analysis (Shrestha, 2021). Bartlett's test of sphericity was significant, with an approximate chi-square ($n = 112$) of 1206, $p < .01$, indicating adequacy for factor analysis. The four factors explained 50.75% of the variance in the data (Kaiser, 1974). The average communality was 0.629, acceptable for sample sizes between 100 and 200 (Samuels, 2017). Reliability analysis using Cronbach's alpha for each extracted factor yielded coefficients of .793, .710, .732, and .712 for factors 1 to 4, respectively. Thus, 22 items were used to assess students' engagement in plane geometry learning between groups and compare them.

2.5. Intervention Procedure

The study initiated an intervention by providing training to the experimental group teacher on the assigned instructional approach. The intervention focused on plane geometry, including theorems on triangles, quadrilaterals, circles, and regular polygons, from a tenth-grade student textbook in the country (Ministry of Education, 2010). The intervention involved assigning experienced teachers, ensuring equal task end time, using similar instructional tools, and covering the same topics to both groups (See Appendix A). The intervention is designed to last for six weeks. The VHGGDIA framework is a five-stage system that integrates guided discovery and Van Hiele's teaching techniques (Achera et al., 2015; Vojkuvkova, 2012).

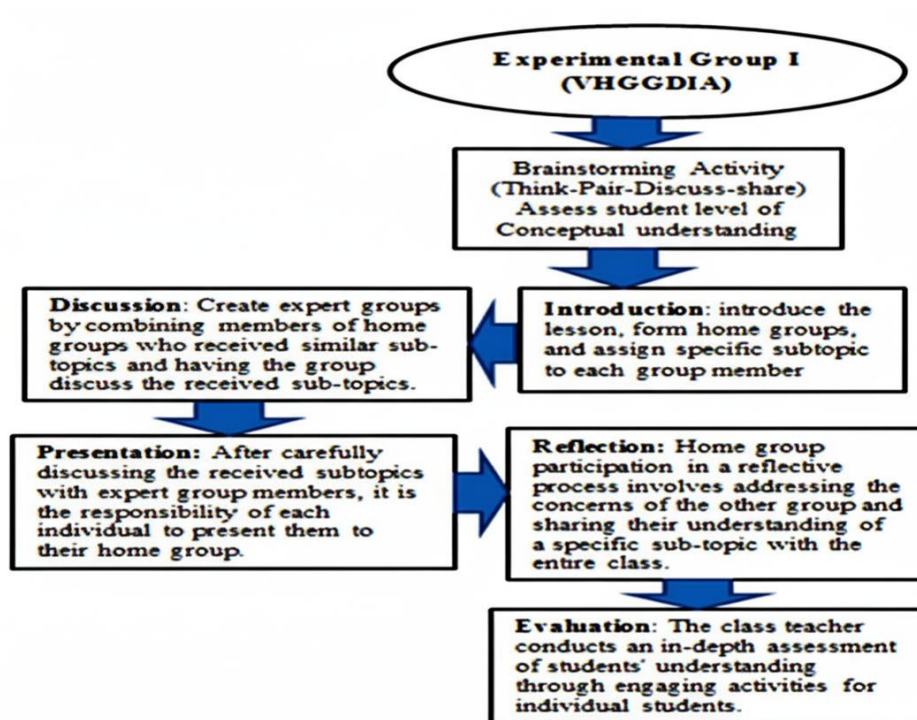


Figure 1. The framework of VHGGDIA

Figure 1 illustrates the phases of VHGGDIA. Using the Think-Pair-Discuss-Share method, initially VHGGDIA inspires students to practice their prior knowledge through a brainstorming activity that calls for peer review, group discussions, and independent thought. Following a thorough rehearsal of the students' prior knowledge, the teacher presents the new material in the following stages: Introduction: To encourage practical work, the teacher splits the class into smaller groups and introduces the new topic by dividing it into subtopics and allocating them to group members using a lottery system. This process comes after a comprehensive rehearsal and activities that require prior knowledge of the new topic. Discussion: By assembling members of home groups allocated to the same subtopics, the teacher encourages students to create further expert groups. These expert groups then conduct in-depth investigations of the subtopics using various instructional resources. Presentation: Each member of the expert group presents what they thoroughly investigated and understood about subtopics to the members of their home group during the discussion stages. Members of

the home group actively participate by summarizing concepts, comprehending one another's viewpoints, and communicating in-depth about their conversations. Reflection: Home groups engage in a reflective process by discussing subtopics collectively, resolving issues, and sharing information. Following this, the teacher summarizes the discussion, and each group presents their ideas, ensuring inclusive participation and addressing any fallacies. Evaluation: The teacher assesses each student's understanding through required tasks and creative assignments, evaluating them individually. The control group's teacher used the talk-and-chalk method as usual.

3. RESULTS AND DISCUSSION

3.1. Results

The study employed various statistical analyses. It used a paired-sample t-test to compare pre-test and post-test mean gain differences within a group. Independent sample t-tests were utilized to assess pre-test mean gain differences between the experimental and control groups. Additionally, ANCOVA was conducted to evaluate mean gain differences after the intervention while controlling for pre-test effects. Every statistical test was used after its assumptions had been carefully evaluated.

3.1.1. Quantitative Result Analysis

Here, the study answered RQ1: Is there a significant mean gain difference between the experimental and control groups before and after the intervention?

Table 3. Pre-descriptive statistics

Group	Period	Components	N	Mean	Skew	Error	Z-value	Kurt	Error	Z-value
Experimental	Pre-test	Cognitive	56	3.62	-.832	.319	-2.61	-.211	.628	-.336
		Behavior	56	4.03	-.656	.319	2.06	-.491	.628	-.782
		Affective	56	3.01	.076	.319	.238	-.386	.628	-.615
		Social	56	3.23	.275	.319	.862	.303	.628	.482
		Aggregate	56	3.47	-.147	.319	-.461	-.436	.628	.694
Control	Pre-test	Cognitive	56	3.69	-.063	.319	-.197	-.822	.628	-1.31
		Behavior	56	3.74	.055	.319	.172	-1.11	.628	-1.76
		Affective	56	3.71	-.052	.319	-.163	-.775	.628	-1.23
		Social	56	3.50	-.181	.319	-.567	-.130	.628	-.207
		Aggregate	56	3.65	-.221	.319	-.693	-.424	.628	-.675

Table 3 shows students in the experimental and control groups had pre-intervention mean scores. These numerical results suggest that the experimental group only outperformed the control group in terms of mean behavioral engagement before the intervention. However, it remains unclear whether this difference is statistically significant. To determine significance, the study employed an independent sample t-test.

The study used an independent sample t-test to compare the mean gains difference between groups before the intervention by testing all assumptions. 1) Observations are independent: the data scored of the entities are independent of each group since the groups are from different schools; 2) the dependent variables are continuous since the researcher uses the

average value as the questionnaire are 5-likert scale; 3) Table 3 shows normal pre-intervention distributions, as z-value < |3.29| (Kim, 2013); 4) Levene's F-test confirms homogeneity of variances ($p > .05$) for each component and combined engagement (see Table 4). All assumptions are met, then the researchers use independent sample t-test.

Table 4. Independent sample t-test for pre-intervention engagement result

Time	Engagement	Levine's test		t-test for equality of means				
		F	Sig.	t	df	Sig.	MD	
Pre-test	Cognitive	Equal variance Assumed	3.480	.064	-.681	110	.479	-.07
		Equal variance not Assumed			-.681	105.95	.479	-.07
	Behavioral	Equal variance Assumed	0.478	.491	2.212	110	.029	.29
		Equal variance not Assumed			2.212	109.99	.029	.29
	Affective	Equal variance Assumed	0.873	.352	-5.81	110	.000	-.70
		Equal variance not Assumed			-5.81	107.57	.000	-.70
	Social	Equal variance Assumed	3.220	.075	-3.40	110	.001	-.27
		Equal variance not Assumed			-3.40	101.27	.001	-.27
	Aggregate	Equal variance Assumed	2.193	.142	-3.05	110	.003	-.18
		Equal variance not Assumed			-3.05	103.64	.003	-.18

Note: MD = Mean difference

Table 4 shows no significant difference in pre-intervention cognitive engagement between the experimental and control groups ($p > .05$). However, significant differences were found in pre-intervention behavioral, affective, social, and combined engagement ($p < .05$). The descriptive statistics indicated that prior to the intervention, the control group exhibited better affective, social, and combined engagement, while the experimental group scored higher in behavioral engagement (see Table 3).

Table 5. Post-descriptive statistics

Group	Period	Components	N	Mean	Skew	Error	Z-value	Kurt	Error	Z-value
Experimental	Post-test	Cognitive	56	4.45	-.111	.319	-.348	-.926	.628	-1.47
		Behavior	56	4.37	-.216	.319	-.677	.002	.628	.003
		Affective	56	3.92	-.092	.319	-.288	-1.02	.628	-1.62
		Social	56	4.22	-.091	.319	-.285	-.616	.628	-.981
		Aggregate	56	4.24	-.022	.319	-.069	-.668	.628	-1.06
Control	Post-test	Cognitive	56	3.95	-.173	.319	-.542	-.801	.628	1.27
		Behavior	56	3.92	-.030	.319	-.094	-.389	.628	.619
		Affective	56	3.15	.223	.319	.699	-.075	.628	-1.119
		Social	56	3.53	.260	.319	.815	-.282	.628	-.449
		Aggregate	56	3.64	.328	.319	1.02	-.469	.628	-.747

Table 5 shows the mean scores of students in the experimental and control groups after the intervention. Notable differences were observed in combined engagement and its components, with the experimental group achieving higher ratings. To assess the significant difference between groups, the study utilized an ANCOVA test while controlling for the pre-test effect.

While making sure all ANCOVA assumptions was checked, the study used an ANCOVA test to examine the mean gains difference between groups after the intervention. Observations are independent because the data from entities are not influenced by the different groups, as they originate from distinct schools. The dependent variables are continuous since the researcher uses the average value, as the questionnaires are 5-point Likert scales. **Table 4** shows normal post-intervention distributions, as $z\text{-value} < |3.29|$ (Kim, 2013). Levene's F-test confirms homogeneity of variances ($p > .05$) for each component and combined engagement (see **Table 6**).

Table 6. Levene's F-test for post-intervention engagement results

Variables	Levene's F-test	df1	df2	Sig.
Cognitive Engagement	3.156	1	110	.078
Behavioral Engagement	4.411	1	110	.056
Affective Engagement	1.083	1	110	.300
Social Engagement	0.606	1	110	.438
Aggregate Engagement	2.716	1	110	.102

The regression model showed that pre-test results and groups were non-significant ($P > .05$); the result met the homogeneity of the regression assumption. The researchers employ an ANCOVA test, as all assumptions were met.

Table 7. ANCOVA test result for post-intervention engagement

Variables	Source	Sum square	df	Mean square	F	Sig.	Partial Eta square
Cognitive Engagement	pretest	.245	1	.245	1.245	.267	.011
	Group	2.137	1	7.137	36.229	.000	.249
	Error	21.473	109	.197			
	Total	2001.040	112				
Behavioral Engagement	pretest	.339	1	.339	1.967	.164	.018
	Group	5.156	1	5.156	29.883	.000	.215
	Error	18.808	109	.173			
	Total	1945.720	112				
Affective Engagement	pretest	.355	1	.355	.965	.328	.009
	Group	14.549	1	14.549	39.534	.000	.266
	Error	40.113	109	.368			
	Total	1459.098	112				
Social Engagement	pretest	.246	1	.246	.866	.354	.008
	Group	13.586	1	13.586	47.802	.000	.305
	Error	30.980	109	.284			
	Total	1719.062	112				
Aggregate Engagement	pretest	.268	1	.268	3.150	.079	.028
	Group	10.238	1	10.238	120.180	.000	.524
	Error	9.286	109	.085			
	Total	1756.119	112				

Table 7 displays the significant mean score differences in post-intervention engagement between groups. The result shows that cognitive ($F(1, 109) = 36.229$, $Sig. < 0.01$, $\eta^2 = .249$), behavioral ($F(1, 109) = 29.883$, $Sig. < 0.01$, $\eta^2 = .215$), affective ($F(1, 109) = 39.534$, $Sig. < 0.01$, $\eta^2 = .266$), social ($F(1, 109) = 47.802$, $Sig. < 0.01$, $\eta^2 = .305$), and engagement ($F(1, 109) = 120.180$, $Sig. < 0.01$, $\eta^2 = .524$). The study further utilized the post hoc Bonnfroni analysis test to identify the group that makes this significant difference.

Table 8. Post hoc Bonnfroni analysis

Variables	Group (I)	Group (J)	Mean difference (I-J)	Sig.
Cognitive Engagement	Experiment Group	Control Group	.632	.000
Behavioral Engagement	Experiment Group	Control Group	.506	.000
Afective Engagement	Experiment Group	Control Group	.438	.000
Social Engagement	Experiment Group	Control Group	.824	.000
Combined Engagement	Experiment Group	Control Group	.733	.000

Table 8 shows significant differences ($p < .05$) in engagement components between the experimental and control groups, indicating that the intervention improved student engagement in learning plane geometry for the experimental group. Further, after adjusting for the covariate (pre-test), the eta-squared effect values demonstrates that the groups' contributions to student engagement varied: 24.9% to cognitive, 21.5% to behavioral, 26.6% to affective, and 30.5% to social engagement, with a total contribution of 52.4% to aggregate student engagement (See Table 7). This value indicates that the treatment had a large effect size (Alwahaibi et al., 2020).

Comparison within a Group on Engagement and its Components

Here, the study answered RQ2: Is there a significant mean gain difference between pre-test and post-test results within a group?

The study utilized a paired sample t-test to examine the transition from pre- to post-intervention engagement. Assumption checks for the paired sample t-test indicated normality (see Tables 3 and 5); independence of observations (no twin observations); and uniform variances in the dependent variable across groups pre- and post- intervention (see Tables 4 and 6). All assumptions were met.

Table 9. Paired sample t-test results in each group

Observation	Group	N	Paired Differences		t	df	Sig.
			Mean difference	SD			
(Post – pre) Cognitive	Experimental	56	.866	.691	9.371	55	.000
	Control	56	.229	.710	2.410	55	.019
(Post – Pre) Behavioral	Experimental	56	.457	.751	4.546	55	.000
	Control	56	.253	.750	2.520	55	.015
(Post – Pre) Affective	Experimental	56	.708	.859	6.163	55	.000
	Control	56	-.531	.752	-5.281	55	.000
(Post – Pre) Social	Experimental	56	.815	.602	10.134	55	.000
	Control	56	-.049	.678	-.542	55	.590

Observation	Group	N	Paired Differences		t	df	Sig.
			Mean difference	SD			
(Post – Pre)	Experimental	56	.711	.382	13.948	55	.000
Aggregate	Control	56	-.025	.390	-0.471	55	.639

The experimental group students confirmed a significant progress in engagement with cognitive ($t(55) = 9.371$, $p < .05$, $d = 1.252$), behavioral ($t(55) = 4.546$, $p < .05$, $d = .608$), affective ($t(55) = 6.163$, $p < .05$, $d = 0.824$), and social ($t(55) = 10.134$, $p < .05$, $d = 1.354$). The control group also showed significant progress in cognitive ($t(55) = 2.410$, $p < .05$, $d = 0.322$) and behavioral engagement ($t(55) = 2.520$, $p < .05$, $d = 0.337$). However, affective engagement in the control group decreased significantly ($t(55) = -5.281$, $p < .05$, $d = -0.706$), and social engagement was non-significant ($t(55) = -0.542$, $p > .05$). As a result, the paired sample t-test showed that the experimental group's student engagement in plane geometry instruction was much higher ($t(55) = 13.948$, $p < .05$, $d = 1.864$), but there was no significant difference in the control group ($t(55) = -0.471$, $p > .05$) (see [Table 9](#)). According to the study, overall engagement and its constituent parts significantly increased in the experimental group, whereas cognitive and behavioral engagement significantly improved in the control group. Significant p-values and a range of effect sizes in the analysis support the intervention's effectiveness in the experimental group. Behavioral engagement shows a medium effect size ($d = 0.608$), whereas cognitive, affective, social, and combined engagement show large effect sizes ($d = 1.252$, $d = 0.824$, $d = 1.354$, and $d = 1.864$, respectively). The data highlights the usefulness of effect size in assessing effectiveness beyond just sample size (McLeod, 2019). In the control group, cognitive engagement ($d = 0.322$) and behavioral engagement ($d = 0.337$) showed significant differences; however, these differences were not forceful.

3.1.2. Observation Results

To evaluate the quantitative findings and examine the effect of the VHGGDIA, the study employed a three-part checklist for ongoing observation throughout the intervention. (1) *Background Information*: Includes details such as name of school, number of students, observation date, time, and round; (2) *Classroom Learning Environment*: Analyzed qualitatively; and (3) *Students' Engagement*: Recorded student behavior during the intervention.

The study observed and recorded student actions 12 times for both groups, analyzing the data using percentages and bar charts. The following are indicators of student engagement in classroom learning: (a) Commitment to exploring plane geometry concepts; (b) Ability to solve problems independently; (c) Attendance in geometry class despite interruptions; (d) Using negative feelings as signals for perseverance or strategy changes; (e) Discussing concepts and collaborating on problem-solving; and (f) Seeking assistance viewed as a tactic rather than a sign of detachment or reliance.

Students were categorized based on the indicators: “Yes” if they showed four or more indicators, “Not Sure” for one to three indicators, and “No” if none were shown.

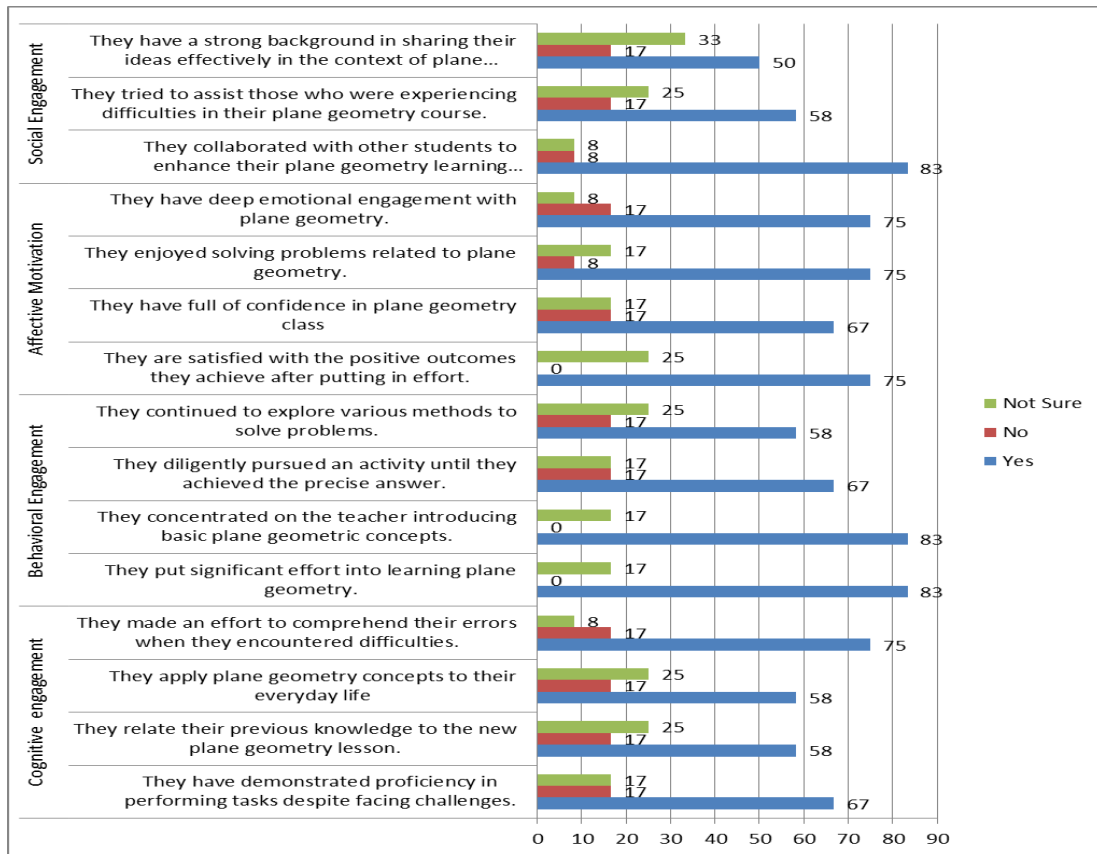


Figure 2. Experimental group student engagement observation result in percent

Figure 2 shows that the VHGGDIA had a positive effect on students' participation with plane geometry, as the experimental group was more likely to get responses indicating strong engagement ("Yes") across all criteria. This finding shows that, even in the face of difficulties, students greatly improve their mental efforts by participating in exercises intended to understand plane geometry topics. Active engagement in classroom learning, which involves practicing past knowledge and connecting it to newly delivered content, facilitates this understanding. Students then attempt to apply this knowledge to tackle real-world problems across various professions.

During the intervention, students demonstrated increased attention to the teacher's presentation, improved respect for others' ideas, and enhanced knowledge sharing. Their effort in completing assignments rose considerably, alongside a notable boost in emotional engagement due to the content's relevance to real-life situations. Students displayed increased confidence in expressing ideas and greater enjoyment in solving challenging problems. The promotion of cooperative work further improved idea sharing and assistance among peers facing difficulties. Overall, observations indicated improvements in students' mental effort, positive behavior, emotional engagement, and collaboration in learning plane geometry.

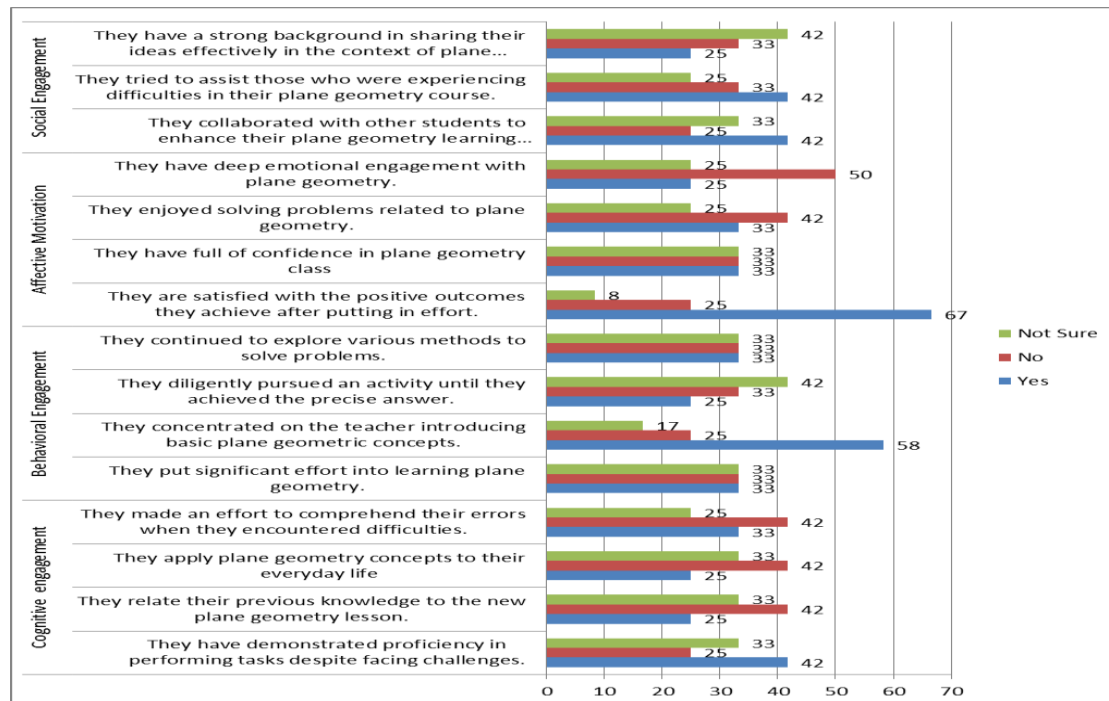


Figure 3. Control group student engagement observation results in percent

The control group's observations revealed little variation in “Yes,” “No,” and “Not Sure” responses, except regarding satisfaction with favorable outcomes and attention during explanations of fundamental concepts, where “Yes” responses were more common (see Figure 3). During class introductions, students exhibited silent behavior and gave positive feedback for accurate responses; however, no visible variations were seen in other engagement criteria. Further, students displayed tardiness, poor communication, and difficulties in understanding concepts, reflecting, solving problems, and cooperating with peers. Overall, the classroom instructional process in the control group went smoothly from the start of the intervention to the end, with students passively following the teacher's instructions by copying notes from the blackboard and the teacher's talk at all times and students’ paying close attention to the teacher's presentation. This result reveals a lack of sustained student engagement, as they did not actively respond to the teacher's questions or thoroughly complete assigned work. Furthermore, students showed poor emotional responses during classroom instruction, and teamwork activities lacked appeal.

3.1.3. Qualitative Data Analysis

The study utilized investigator observations and teacher interviews to evaluate the effectiveness and difficulties of implementing an existing teaching technique.

Here, the study answered RQ3: How do the VHGGDIA improve student engagement in learning plane geometry?

The study performed interviews with the participating teachers both before and after the intervention, coding them as TT1 = Experimental Group teacher and TT2 = Control Group teacher. The qualitative result centers on two main themes: student participation and the effectiveness of teaching approach expected at enhancing this participation.

Teacher Interviews

Guided Question 1: *Do your students actively participate in geometry instruction? If not, why? If yes, how?*

Before the Intervention:

The interview result indicates that students' engagement in studying plane geometry is low due to their limited prior knowledge (cognitive) and the teacher's inability to encourage teamwork in classroom preparation (social). While some students peacefully listen to the teacher's lecture by receiving teacher notes, others cause disruptions in the classroom (behavioral). Instead of actively interacting with the teacher to broaden their knowledge, students showed low commitment to finishing their tasks and consistently relied on the teacher to finish lectures (affective). Exams at the conclusion of each chapter are used by teachers to assess their students, which causes them to prioritize test-taking above regular practice for long-term understanding.

The following sample quote shows participant teachers direct responses before the intervention. TT1 said, "As I observed what I taught in grade nine before, students are not actively participating in the class discussion." The study asked why? TT1 further explained, Students' lack of prior knowledge in plane geometry caused them to behave silently and participate poorly rather than actively participate in classroom discussions, as well as due to time constraints, teachers did not encourage their students to participate (TT1, 23 March 2023, 8:30).

TT2 explained,

I categorize my students into three groups: diligent: who follow lessons and actively participate in the class; this group has a limited in number. Intermediate: students often have limited background knowledge and take time to understand concepts, which can reduce their participation. Low-involvement: who struggle due to a weak foundation they feel mathematics has the most difficult subject; this group contains the maximum number (TT2, 24 March 2023, 8:30).

After the Intervention:

From the interview responses, the VHGGDIA enhanced student engagement by integrating new concepts with prior knowledge. The teacher initially encouraged students to practice their prior knowledge by thinking independently and sharing their thoughts with others (cognitive). This initial phase increased student involvement in learning new content, with the teacher closely monitoring their progress (Behavioral). The lesson involves group discussions with each group member contributes new ideas to the next group after a comprehensive understanding of the group discussion (social). The new method increased students' confidence, which strengthened their understanding and increased their responsibilities to share their knowledge with others (affective). However, the interview results for the control group showed no improvement over their pre-intervention beliefs. This suggests that the conventional teaching approach did not encourage students to participate in class by putting forth mental effort, did not exhibit appropriate behavior for teacher instruction, was emotionally insufficient for learning, and did not promote teamwork.

The following sample quote shows participant teachers direct responses after the intervention. TT1 stated, “Students' participation greatly improved by integrating their previous knowledge with new ideas. This improvement supported by the teaching method that encourages peer sharing, group debates, critical thinking, and class presentations. The strategy improved student confidence. How?

TT1 responded that

As a result of the teacher's guidance, students' dedication to debate and concept exploration meaningfully rose as they thought independently (cognitive), as well as group discussions to express their feelings (affective). They spend all of their time developing the best plan of action when activities are challenging for them (behavioral). Students' confidence increased as they began to openly seek help from their instructor to address their challenges (social).

TT1 further mentioned

"students are actively participating in classroom instruction to complete tasks and prevent any disruptions (behavioral)" (TT1, 25 May 2023, 8:30).

TT2 stated,

“Students did not actively participate in classroom discussion.” Why? Further, TT2 rose,
Because from the start at the lower grade level, their teacher's do not encourage their students to take on tasks independently, and even when they do, the teacher does not invite them openly share what they have accomplished with their peers and teachers. In addition, due to time constraint the teacher including me prioritizes completing a concept without student participation, leading to decreased students' self-confidence and a lack of necessary background knowledge. This issue has reduced students' current engagement in learning plane geometry (TT2, 26 May 2023, 8:30).

Prior to the intervention, both interviewees reported similar results indicating low mental effort, negative classroom behavior, emotional exhaustion, and poor collaboration among students learning plane geometry. Teachers' opinions on student participation in the classroom vary after the intervention. This discrepancy mostly originates from the different tactics employed by teachers. The group that utilized the VHGGDIA approach in teaching plane geometry demonstrated more improvement in student engagement than the group that relied on traditional teaching methods.

Guided Question 2: *Do you believe that the teaching strategy currently applied in plane geometry instruction has positive effects on student engagement?*

Before the Intervention:

The interviews result shows the teachers in both groups acknowledge using a more teacher-centered style of instruction before the intervention. Both teachers argue that this type of teaching will not significantly increase students' interest in classroom learning. They also

gave a reason for their dislike of the method, claiming that it did not force learners to practice under difficult circumstances or improve their capacity for independent work or verbal communication. The student's commitment in using an alternative approach to problem-solving is lacking. Because they expect the teacher to answer challenging problems for them, students are always dependent on studying solved problems rather than solving them on their own. Further, the respondents cited the following reasons for their teacher-centered approach: the size of the classroom, the students' lack of prior knowledge, and their inexperience with active teaching.

The interview provided a sample quote that demonstrates the respondents' direct responses. TT1 said, "I used a teacher-centered approach to instruction. I think that this kind of instruction did not fully stimulate students' engagement in studying mathematics." Do you think that students' engagement improves when they actively participate in learning plane geometry? TT1 said, "Yes! Students that actively participate in plane geometry class have far higher levels of engagement." So, why you do not employ an active teaching strategy to improve student engagement instead of a teacher-centered approach? TT1 said, "Because active teaching strategies are time-consuming, hindered by students' lack of background knowledge, and require careful implementation" (TT1, 23 March 2023, 8:30). TT2 stated, "I most likely taught using a teacher-centered approach, which does not provide students enough time to contribute fully to class discussions." Why you did not provide students adequate time to participate in class? TT2 stated, "It is difficult to fully engage students in the teaching of plane geometry because of time restrictions and a lack of student's prior knowledge" (TT2, 24 March 2023, 8:30).

Prior to the intervention, interviewees employed a teacher-centered teaching approach, claiming that students' lack of prior knowledge was the reason behind their choice. Both reviewers advocated for implementing an active learning strategy specifically for students who possess adequate prior knowledge at their respective grade levels. If students lack background knowledge, their classroom participation suffers, requiring significant teacher effort and time, this complicates covering the curriculum within the school year. For these reasons, both interviewees used the teacher-centered approach to finish the text without asking students to practice during class.

After the Intervention:

The VHGGDIA greatly improved student engagement, as evidenced by the interview from the respondent who implemented it. According to interviewee's comments, the new teaching strategy calls for students to practice their prior knowledge by thinking independently and sharing their thoughts with others. The strategy encourages students to think individually, share their ideas, and receive new information from others. Successively, students' dependency on teachers decreases, increasing self-confidence and commitment to learning. Classroom disturbances decrease since students engage in activities to fulfill responsibilities. The increment of students' self-confidence motivates them to investigate different approaches to solve problem, which reduces frustration and pushes them to attempt new methods rather than depending solely on inaccurate answers. Students actively seek alternative solutions rather than waiting for teacher. The group discussion strengthens their joint activities to accomplish

the essential shared objectives. The conventional teaching approach did not show any significant difference in the group.

The interview provided an example quote that demonstrates the respondents' direct responses.

TT1 said,

Before the intervention I considered the student-centered teaching approach to be overly time-consuming. However, this teaching method effectively helps students retain and understand their background knowledge by providing sufficient time to learn new ideas within a specific time limit. This method facilitates students' understanding of necessary knowledge by encouraging active participation.

How do you think this approach improved student engagement? TT1 said, "In my opinion, the strategy encouraged active participation, reminding students background knowledge, and relating the lesson to everyday lives significantly increased student engagement by lowering frustration and reducing dependence" (TT1, 25 May 2023, 8:30).

TT2 stated,

As I previously said in the pre-intervention interview, I taught plane geometry subjects using a teacher-focused teaching approach. However, due to their perception that the plane geometry concept is the most challenging topic, most students are silent listeners rather than actively participate in the class discussion.

Why you did not try to invite your students actively participate in the class? TT2 said, Sometimes, I pose questions and provide subjects that promote group discussion. However, Instead of paying attention to group work, students frequently joke around and neglect to respond to questions. Because of time wastage and poor outcomes, I usually used teacher-oriented teaching strategies (TT2, 26 May 2023, 8:30).

Observation Results:

The study utilized an observation checklist to continuously monitor the intervention's impact on student engagement. The study utilized the indicators of classroom activities that support the development of students' engagement: the teacher inspires student discussion, values students' opinions, assigns tasks, and supports students' progress using relevant guidelines. Students followed the teacher's instructions and practiced using different ways to learn new concepts. They committed to group discussions, developed their ability to work independently by requiring less assistance from their teacher to complete assignments, carefully followed classroom instructions, and tried out different approaches to problems.

Initial observations reveal insufficient group sizes, inadequate teacher support for practical work, low student engagement, and poor teacher-student communication in both groups. The experimental group demonstrated enhanced teacher-appropriate guidance, assessment, and student interaction over time, unlike the control group.

Observation during the intervention period revealed that the experimental group teacher encourages students to thoroughly practice their prior knowledge and facilitates group discussion for new content. After carefully going over their existing knowledge, the students participated in a cooperative discussion. Due to their thorough understanding of the group discussion, students realized their dedication to finishing assignments and presenting them to the classroom. Over time, the use of confidential class discussions, reflections, presentations, and questioning has facilitated students' freedom to enhance their learning experiences. The classroom environment's safety was enhanced as students focused on completing their tasks without disrupting the class.

The teacher for the control group uses the chalkboard to display notes as they teach their course. Some students disturb class during the teacher's presentation, while others take notes without paying close attention. Instead of inviting students to participate in class discussions, it is typical for the teacher to complete all tasks alone. Teachers sometimes assigned classwork, homework, and group discussions, but students often failed to complete tasks, leading to increased laziness and decreased participation in group discussions. The teacher failed to evaluate students' classwork, homework, and group work, resulting in a classroom environment that did not encourage active participation.

Teachers in both groups expressed concerns about students' low engagement with plane geometry and provided explanations for their lack of engagement. Students' disengagement in classroom instruction is primarily due to poor background knowledge, belief in math as difficult, excessive classroom size, and lack of experience in active teaching strategies. The post-intervention results demonstrated that the experimental group students' dedication to both individual and group activities shows an improvement and that their confidence raised by reducing the need for more teacher assistance. The control group's pre-intervention and post-intervention teacher interview results were similar. The outcomes of the observation also supported these outcomes.

3.2. Discussion

This study tested the differences between groups before and after an intervention and analyzed the pre-test and post-test outcome differences within a group. It concentrated on the effect of the intervention on students' engagement in learning plane geometry, leading to discussions and recommendations based on the findings.

The pre-descriptive statistics showed that the control group scored high affective, social, and combined engagement, while the experimental group scored high behavioral engagement (See [Table 3](#)). The independent sample t-test showed on the pre-intervention data indicated significant mean score differences in engagement and its three components. However, there was no difference in cognitive engagement between the experimental and control groups (See [Table 4](#)). The result revealed that control group students exhibited more favorable emotional responses and interactions with teachers and peers, whereas the experimental group demonstrated more positive behavior towards learning plane geometry. However, there was no difference in mental effort between the experimental and control groups in learning and applying effective methods for acquiring plane geometry. Due to communication issues, inadequate teaching methods, and gaps in prior knowledge, early

assessments show that students are not engaged in learning mathematics (Brezavšček et al., 2020; Kocagul, 2024). To enhance academic performance, the authors highlight the importance of effective secondary school instruction for support basic knowledge, boosting self-confidence in learning mathematics, and alleviating fear. They advocate for both in-class and extracurricular activities to promote engagement and emphasize the significance of teacher-student interaction. Before the intervention, descriptive statistics indicated that student average responses were predominantly neutral across all items, suggesting unclear views of learning plane geometry among students.

Following the intervention, the ANCOVA test indicated a significant difference in student engagement between the experimental and control groups after adjusting for the pre-test effect (see Table 7). In comparison to the control group, the experimental group outperformed it in post-descriptive statistics results; exhibiting higher mean ratings for all components and combined engagement (see Table 5). Additionally, the Bonferroni test revealed that the VHGGDIA significantly outperformed the conventional teaching strategy in terms of raising student engagement in plane geometry learning ($p < .001$). After the intervention, descriptive statistics also indicated that students in the experimental group predominantly agreed with all items, suggesting they had positive views of learning plane geometry. The result was consistent with the research finding by Çelik that activity-based instruction in mathematics has greater academic success than traditional methods, with the experimental group achieving higher posttest scores due to increased motivation and engagement from hands-on activities (Çelik, 2018). Contrary to the results of this study, students who used the activity-based method showed a decrease in favorable attitudes toward mathematics instruction, whereas the control group showed an improvement (Çelik, 2018). In contrast, students in the control group showed views similar to their pre-intervention data, with only a few improvements in cognitive and behavioral engagement components (see Table 5).

The outcome indicates that to enhance their understanding of the content being taught, the experimental group exerted greater cognitive effort by critically reflecting on their class discussions and applying their prior knowledge. Most students shared their opinions in group discussions, clearly demonstrating their commitment to sharing knowledge with both their peers and the entire class. Behaviorally, there has been a noticeable improvement in students' commitment to completing the task assigned by the classroom teacher using different resources, completing the assignment on time, and paying attention to the teacher's directions. Students' disruptive behavior significantly decreased; instead, they participated in group discussions to finish the teacher's assignment and developed a greater appreciation for the opinions of others. The majority of students successfully completed the tasks assigned by the teacher. Additionally, students' affective (emotional) responses to the classroom instruction significantly improved, since the teaching illustrated the connection between the content and their everyday activities and how they would view its value in their everyday lives. The students' eagerness for the plane geometry lesson was enhanced by the teacher's allotted job, since the given task had a great impact on their participation in class. Furthermore, the intervention encouraged group contribution by promoting the sharing of ideas and assigning specific responsibilities to each individual. This activity encourages students to engage socially in classroom instruction by sharing ideas and respecting each other's concerns to

address any misconceptions that arise. In the group discussion, each individual actively participated by presenting their knowledge, asking questions for clarification, and ensuring mutual understanding of all aspects of the discussion. This activity enhanced students' confidence in presenting their contributions from the group discussion and promoted social interaction.

This study finding closely related to the result obtained by different researchers as Students instructed via the Van Hiele model demonstrated notable gains in achievement scores, better proficiency in non-routine geometric proofs, and improved learning through exploration and reasoning compared to traditional methods (Alex & Mammen, 2016; Connolly, 2010; Machisi & Feza, 2021). Similarly, when compared to traditional methods, the guided discovery strategy enhanced students' mathematical reasoning skills, communication abilities, and self-confidence in addition to successfully reducing their reliance on rote memorization in geometry, which is consistent with this research finding.

Likewise, the paired sample t-test result exposed a significant rise in engagement among students in the experimental group from pre-test to post-test in plane geometry. Key factors contributing to this improvement included timely assignment completion, active in extracurricular activities, better teamwork, and increased emotional commitment to learning. Cognitively engaged students excel in applying knowledge to problem-solving, improved critical thinking, and tackling challenging assignments. Attention to teacher instruction, active pursuit of goal-oriented tasks and investigation of problem-solving techniques are all components of behavioral engagement. Affective engagement rises when students enjoy solving problems, are curious about positive outcomes, and confidently share their ideas in class. This improvement verified benefits of traditional teaching method in enhancing students' cognitive, behavioral, and affective engagement. However, students using the VHGGDIA method showed greater engagement in studying plane geometry compared to those using the traditional teaching strategy. This outcome supports Azuka Benard Festus's findings that active participation improves students' understanding and retention in mathematics. Teachers are encouraged to move from traditional methods to those promoting active learning, as student involvement is crucial for effective math development. Classrooms that foster peer support and provide autonomy lead to better engagement openings for students (Bizimana, 2025; Festus, 2013).

Overall, the study indicates that the VHGGDIA significantly enhances student engagement in learning plane geometry compared to traditional methods. It highlights collaboration, prior knowledge review, and active participation as key components of this effective teaching approach. The partial eta squared (η^2) measures the proportion of variance explained by independent variables in the dependent variable (Gravetter & Wallnau, 2017). In this context, groups accounted for 24.9% of variance in cognitive engagement, 21.9% in behavioral engagement, 26.6% in affective engagement, 30.6% in social engagement, and 52.4% in overall engagement. These effect sizes are considered large treatment effects in accordance with the parameters proposed by Alwahaibi et al. (2020). This result aligns with research by Adams and Enu (2023), Akintade et al. (2024), and Juman et al. (2022), which found student-centered teaching strategies to be more effective than traditional method in improving student academic performance.

Research shows a strong correlation between student engagement and academic potential, highlighting its importance in the learning process. Engagement includes active participation in behavioral, emotional, and cognitive dimensions, which contribute to both academic and social success (Cesnaviciene et al., 2022). Supporting evidence from Santos et al. (2022) and quasi-experimental studies by Ramdhani et al. (2017) also indicated that guided discovery learning method significantly benefit students' performance in geometry. Improving student learning engagement has a major influence on the relationship between heuristics, emotion, and mathematics problem-solving (Shimizu, 2025). The findings further aligned with Chianson et al. (2011), indicating that using cooperative learning retained circle geometry concepts better than those taught via conventional methods. Further, cooperative learning improves students' presentation and attitudes in mathematics learning (Ndebil & Ali, 2024).

How the VHGGDIA can boost students' engagement in studying plane geometry is the study's final focus. Initially, students showed low engagement in plane geometry, attributed to limited prior knowledge, inadequate teamwork help, and disruptions. Heavy reliance on teachers and low task commitment, along with assessment methods focused on testing rather than understanding, further exacerbate the issue. Observations indicate problems such as inadequate group sizes, insufficient teacher support for practical work, limited activity time, and poor communication, and these practices hindering engagement. Research emphasizes that student engagement is crucial for learning outcomes, with engaged students achieving higher grades compared to their disengaged peers (Bear et al., 2019; Maamin et al., 2021). Following to the intervention, the VHGGDIA promotes independent thinking, peer sharing, debates, critical thinking, and presentations, encouraging greater creativity in students' learning. Under teacher guidance, students improved in cognitive dedication to debate and independent thought, engaged affectively in group discussions, and developed effective plans for challenging activities. They also showed increased confidence by seeking help from instructors and participated actively in class to complete tasks. This strategy fosters engagement by linking new concepts to prior knowledge, enhancing student confidence and independence while encouraging collaborative work. This engagement leads to reduced disruptions in the classroom and promotes creative problem-solving, as students seek diverse strategies and cooperate in discussions. Additionally, it connects lessons to real life, minimizing frustration and reliance on teachers, while the teacher facilitates cognitive independence and monitors progress to boost participation. The lesson concludes with group discussions that improve collective work. Research shows that student engagement is crucial for motivation, participation in school activities, achievement of learning goals, and overall development (Shih, 2021; Wang & Tambi, 2024).

4. CONCLUSION

The purpose of the study was to find out how VHGGDIA affected secondary school students' engagement in learning plane geometry in Hawassa, Ethiopia. The study revealed that VHGGDIA, incorporating Van Hiele theory and guided discovery learning theory, significantly enhances student engagement in learning plane geometry compared to traditional teaching methods. VHGGDIA greatly enhances student engagement in learning plane

geometry, with marked improvements from pre-test to post-test reflected in substantial effect sizes. After controlling for pre-intervention engagement, the study revealed statistically significant differences in post-intervention engagement between the experimental and control groups.

The qualitative results indicated that students held varying opinions on enhancing their engagement prior to new content introduction. These opinions included independent thinking to review prerequisite information, followed by the careful presentation of their ideas to peers and the class, which significantly motivated students to learn new material. The teacher promotes group discussions to boost student engagement across cognitive, behavioral, affective, and social dimensions after evaluating prerequisites. Cognitively, students use mental effort to find out new information; behaviorally, they share ideas without disturbing the class and show respect for teachers by finishing assignments on time; affectively, they participate in private discussions by viewing them as crucial for solving problems in the future; and socially, they respect and share ideas with peers. To address a problem, the relationship between learning resources and circumstances is considered in the context of plane geometry. All things considered, VHGGDIA is an effective student-centered teaching approach that encourages students' engagement in plane geometry so they can come up with unique solutions to challenging mathematical issues. As a result, the current study found that VHGGDIA significantly enhances tenth-grade students' engagement in learning plane geometry compared to traditional.

Acknowledgments

The authors express gratitude to three secondary school administrators, tenth-grade students, and mathematics teachers for their support and cooperation. Second, we would like sincerely thank the writers and scholars whose works we referenced throughout this study. The Ministry of Education, Bahir Dar University, and the administrators of Hawassa College of Teachers Education are sincerely grateful for their invaluable assistance.

Declarations

- Author Contribution : AAG: Conceptualization, Data curation, Formal analysis, Resources, Writing - original draft, and Writing - review & editing; MAA: Writing - review & editing; AMA: Writing - review & editing.
- Funding Statement : The authors received no external financial support for this article. However, Bahir Dar University provided support with transportation and stationery costs.
- Conflict of Interest : The authors declare no conflict of interest.
- Additional Information : Additional information is available for this paper.

REFERENCES

- Abla, C., & Fraumeni, B. R. (2019). *Student engagement: Evidence-based strategies to boost academic and social-emotional results*. McREL International.
- Achera, L. J., Belecina, R. R., & Garvida, M. D. (2015). The effect of group guided discovery approach on the performance of students in geometry. *International Journal of Multidisciplinary Research and Modern Education (IJMRME)*, 1(2), 331–342.
- Adams, M., & Enu, J. (2023). Impact of activity-based instruction on grade 11 learners' achievement in plane geometry. *African Journal of Educational Studies in Mathematics and Sciences*, 19(1), 19–28.
- Adler, J., & Sfard, A. (2016). *Research for educational change: Transforming researchers' insights into improvement in mathematics teaching and learning*. Routledge.
- Akintade, C. A., Ogunrinade, S. O., & Awe, I. A. (2024). Effectiveness of geometrical instructional teaching strategy on junior secondary school students' achievement, gender and attitude in plane geometry in odeda local government, Ogun state, Nigeria. *International Journal of Science and Research Archive*, 11(2), 1306–1315. <https://doi.org/10.30574/ijrsra.2024.11.2.0485>
- Alex, J. K., & Mammen, K. J. (2016). Lessons learnt from employing Van Hiele theory based instruction in senior secondary school geometry classrooms. *Eurasia Journal of Mathematics, Science and Technology Education*, 12(8), 2223–2236. <https://doi.org/10.12973/eurasia.2016.1228a>
- Alrajeh, T. S., & Shindel, B. W. (2020). Student engagement and math teachers support. *Journal on Mathematics Education*, 11(2), 167–180. <https://doi.org/10.22342/jme.11.2.10282.167-180>
- Alwahaibi, I. S. H., Al-Hadabi, D. A. M., & Al-Kharousi, H. A. T. (2020). Cohen's criteria for interpreting practical significance indicators: A critical study. *Cypriot Journal of Educational Sciences*, 15(2), 246–258. <https://doi.org/10.18844/cjes.v15i2.4624>
- Balim, A. G. (2009). The effects of discovery learning on students' success and inquiry learning skills. *Eurasian Journal of Educational Research (EJER)*(35), 1–20.
- Bear, G. G., Harris, A., Saraiva de Macedo Lisboa, C., & Holst, B. (2019). Perceptions of engagement and school climate: Differences between once-retained and multiple-retained students in Brazil. *International Journal of School & Educational Psychology*, 7(1), 18–27. <https://doi.org/10.1080/21683603.2017.1376725>
- Belay, S., Atnafu, M., Michael, K., & Ermias, M. A. (2016). *Strategic policy for national science, technology and mathematics education*. Japan International Cooperation Agency (JICA).
- Bizimana, E. (2025). Student engagement in learning: Exploring the role of perceived student cohesiveness, equity, teacher support, and teacher autonomy support under the framework of self-determination theory. *International Journal of Changes in Education*, 3(1), 49–60. <https://doi.org/10.47852/bonviewIJCE52024500>
- Brezavšček, A., Jerebic, J., Rus, G., & Žnidaršič, A. (2020). Factors influencing mathematics achievement of university students of social sciences. *Mathematics*, 8(12), 2134. <https://doi.org/10.3390/math8122134>
- Bruner, J. S. (1961). *The act of discovery*. Harvard educational review.

- Çelik, H. C. (2018). The effects of activity based learning on sixth grade students' achievement and attitudes towards mathematics activities. *Eurasia Journal of Mathematics, Science and Technology Education*, 14(5), 1963–1977. <https://doi.org/10.29333/ejmste/85807>
- Cesnaviciene, J., Buksnyte-Marmiene, L., & Brandisauskiene, A. (2022). The importance of teacher support and equity in student engagement and achievement in low SES school contexts. *The New Educational Review*, 69(3), 157–169. <https://doi.org/10.15804/tner.2022.69.3.12>
- Chianson, M. M., Kurumeh, M. S., & Obida, J. A. (2011). Effect of cooperative learning strategy on students' retention in circle geometry in secondary schools in Benue State, Nigeria. *American Journal of Scientific and Industrial Research*, 2(1), 33–36. <https://doi.org/10.5251/ajsir.2011.2.1.33.36>
- Connolly, S. (2010). *The impact of Van Hiele-based geometry instruction on student understanding*. Mathematical and Computing Sciences Masters.
- Creswell, J. W., & Creswell, J. D. (2018). Mixed methods procedures. *Research Defign: Qualitative, Quantitative, and Mixed Methods Approaches*, 31(3), 75–77.
- Dorra, B. T. (2021). *Exploring the challenges of teaching similarity of triangles, the case of Areka town primary schools, Ethiopia*. University of South Africa. <https://ir.unisa.ac.za/handle/10500/28479>
- Emanet, E. A., & Kezer, F. (2021). The effects of student-centered teaching methods used in mathematics courses on mathematics achievement, attitude, and anxiety: A meta-analysis study. *Participatory Educational Research*, 8(2), 240–259. <https://doi.org/10.17275/per.21.38.8.2>
- Fabiyi, T. R. (2017). Geometry concepts in mathematics perceived difficult to learn by senior secondary school students in Ekiti State, Nigeria. *IOSR Journal of Research & Method in Education (IOSR-JRME)*, 7(1), 83–90. <https://doi.org/10.9790/7388-0701018390>
- Festus, A. B. (2013). Activity-based learning strategies in the mathematics classrooms. *Journal of Education and Practice*, 4(13), 8–14.
- Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, 74(1), 59–109. <https://doi.org/10.3102/00346543074001059>
- Fredricks, J. A., Wang, M.-T., Linn, J. S., Hofkens, T. L., Sung, H., Parr, A., & Allerton, J. (2016). Using qualitative methods to develop a survey measure of math and science engagement. *Learning and Instruction*, 43, 5–15. <https://doi.org/10.1016/j.learninstruc.2016.01.009>
- Garner, B. (2015). *Impact of student-centered learning in mathematics*. Doctoral dissertation, Wittenberg University.
- Goodwin, B., & Hubbell, E. R. (2013). *The 12 touchstones of good teaching: A checklist for staying focused every day*. ASCD.
- Gravetter, F. J., & Wallnau, L. B. (2017). *Statistics for the behavioral sciences*. Cengage Learning.
- Hidayati, N. A., Fahmi, S., & Farida, K. (2019). The comparative of mathematics learning using guided discovery method and expository method to mathematics learning outcomes. *Journal of Physics: Conference Series*, 1321(3), 032103. <https://doi.org/10.1088/1742-6596/1321/3/032103>

- Jablonski, S., & Ludwig, M. (2023). Teaching and learning of geometry—A literature review on current developments in theory and practice. *Education Sciences*, 13(7), 682. <https://doi.org/10.3390/educsci13070682>
- Jansen, A. (2020). Engagement with mathematics. In S. Lerman (Ed.), *Encyclopedia of mathematics education* (pp. 273–276). Springer International Publishing. https://doi.org/10.1007/978-3-030-15789-0_100040
- Juman, Z. A. M. S., Mathavan, M., Ambegedara, A. S., & Udagedara, I. G. K. (2022). Difficulties in learning geometry component in mathematics and active-based learning methods to overcome the difficulties. *Shanlax International Journal of Education*, 10(2), 41–58.
- Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika*, 39(1), 31–36. <https://doi.org/10.1007/BF02291575>
- Kim, H.-Y. (2013). Statistical notes for clinical researchers: Understanding standard deviations and standard errors. *Restorative dentistry & endodontics*, 38(4), 263–265. <https://doi.org/10.5395/rde.2013.38.4.263>
- Kocagul, M. (2024). Learning activity matters: Tips for student engagement. *Participatory Educational Research*, 11(1), 1–15. <https://doi.org/10.17275/per.24.1.11.1>
- Latif, A., Bano, H., & Muhammad, N. (2025). Student engagement in classrooms: A study of cognitive and behavioral engagement across different subject areas. *Journal of Applied Linguistics and TESOL (JALT)*, 8(3), 70–77. <https://doi.org/10.63878/jalt907>
- Lei, H., Cui, Y., & Zhou, W. (2018). Relationships between student engagement and academic achievement: A meta-analysis. *Social Behavior and Personality: an international journal*, 46(3), 517–528. <https://doi.org/10.2224/sbp.7054>
- Maamin, M., Maat, S. M., & Iksan, Z. H. (2021). The influence of student engagement on mathematical achievement among secondary school students. *Mathematics*, 10(1), 41. <https://doi.org/10.3390/math10010041>
- Machisi, E., & Feza, N. N. (2021). Van Hiele theory-based instruction and grade 11 students' geometric proof competencies. *Contemporary Mathematics and Science Education*, 2(1), ep21007. <https://doi.org/10.30935/conmaths/9682>
- McLeod, S. A. (2019). What does effect size tell you. *Simply psychology*, 10, 1–3.
- Mentari, W. N., & Syarifuddin, H. (2020). Improving student engagement by mathematics learning based on contextual teaching and learning. *Journal of Physics: Conference Series*, 1554(1), 012003. <https://doi.org/10.1088/1742-6596/1554/1/012003>
- Ministry of Education. (2010). *Mathematics grade ten-student textbook*. The Federal Democratic Republic of Ethiopia.
- Ministry of Education. (2021). *Education sector development programmed VI (ESDP VI) (2013 2017 E.C. 2020/21 – 2024/25 G.C.)*. The Federal Democratic Republic of Ethiopia.
- Moenikia, M., & Zahed-Babelan, A. (2010). A study of simple and multiple relations between mathematics attitude, academic motivation and intelligence quotient with mathematics achievement. *Procedia - Social and Behavioral Sciences*, 2(2), 1537–1542. <https://doi.org/10.1016/j.sbspro.2010.03.231>

- NCTM. (2000). *Principles and standards for school mathematics*. National Council of Teachers of Mathematics.
- Ndebil, M. B., & Ali, C. A. (2024). Cooperative learning as a strategy of improving mathematics performance and attitudes. *International Journal of Educational Innovation and Research*, 3(1), 62–74. <https://doi.org/10.31949/ijeir.v3i1.7163>
- Nyman, M. (2020). *What do students' feel about mathematics?: Compulsory school students' emotions and motivation towards mathematics*. Doctoral dissertation, Stockholms universitets förlag.
- Ramdhani, M. R., Usodo, B., & Subanti, S. (2017). Discovery learning with scientific approach on geometry. *Journal of Physics: Conference Series*, 895(1), 012033. <https://doi.org/10.1088/1742-6596/895/1/012033>
- Remillard, H. A. (2015). *The effect of cooperative learning on middle school math students*. Heritage University.
- Samuels, P. (2017). *Advice on exploratory factor analysis*. Birmingham City University.
- Santos, M. S. M. D., Sobretudo, M. L., & Hortillosa, A. D. (2022). The Van Hiele model in teaching geometry. *World Journal of Vocational Education and Training*, 4(1), 10–22. <https://doi.org/10.18488/119.v4i1.3087>
- Shernoff, D. J., Kelly, S., Tonks, S. M., Anderson, B., Cavanagh, R. F., Sinha, S., & Abdi, B. (2016). Student engagement as a function of environmental complexity in high school classrooms. *Learning and Instruction*, 43, 52–60. <https://doi.org/10.1016/j.learninstruc.2015.12.003>
- Shernoff, D. J., Ruzek, E. A., & Sinha, S. (2017). The influence of the high school classroom environment on learning as mediated by student engagement. *School psychology international*, 38(2), 201–218. <https://doi.org/10.1177/0143034316666413>
- Shih, S.-S. (2021). Factors related to Taiwanese adolescents' academic engagement and achievement goal orientations. *The Journal of Educational Research*, 114(1), 1–12. <https://doi.org/10.1080/00220671.2020.1861584>
- Shimizu, Y. (2025). Learning engagement as moderator between self-efficacy, math anxiety, use of diagrams, and complex plane problem-solving. *Eurasia Journal of Mathematics, Science and Technology Education*, 21(2), em2586. <https://doi.org/10.29333/ejmste/15956>
- Shrestha, N. (2021). Factor analysis as a tool for survey analysis. *American Journal of Applied Mathematics and Statistics*, 9(1), 4–11. <https://doi.org/10.12691/ajams-9-1-2>
- Singh, N. A., & Kumar, N. (2022). Geometry and its uses in day to day life. *International Research Journal of Modernization in Engineering Technology and Science*, 4(5), 2703–2709.
- Siregar, N. C., Rosli, R., & Maat, S. M. (2020). The effects of a discovery learning module on geometry for improving students' mathematical reasoning skills, communication and self-confidence. *International Journal of Learning, Teaching and Educational Research*, 19(3), 214–228. <https://doi.org/10.26803/ijlter.19.3.12>
- Skilling, K., Bobis, J., Martin, A. J., Anderson, J., & Way, J. (2016). What secondary teachers think and do about student engagement in mathematics. *Mathematics Education Research Journal*, 28(4), 545–566. <https://doi.org/10.1007/s13394-016-0179-x>

- Subagis, J. (2021). Discovery learning rise student's activeness and understanding compound figure area. *Journal of Physics: Conference Series*, 1957(1), 012014. <https://doi.org/10.1088/1742-6596/1957/1/012014>
- Subban, P. K., & Round, P. (2015). Differentiated instruction at work. Reinforcing the art of classroom observation through the creation of a checklist for beginning and pre-service teachers. *Australian Journal of Teacher Education*, 40(5), 117–131. <https://doi.org/10.14221/ajte.2015v40n5.7>
- Suratno, J., Tonra, W. S., & Ardiana, A. (2019). The effect of guided discovery learning on students' mathematical communication skill. In *The 2nd International Conference on Science, Mathematics, Environment, and Education*, (Vol. 2194, pp. 020119). <https://doi.org/10.1063/1.5139851>
- Tanujaya, B., Prahmana, R. C. I., & Mumu, J. (2017). Mathematics instruction, problems, challenges and opportunities: A case study in Manokwari regency, Indonesia. *World Transactions on Engineering and Technology Education*, 15(3), 287–291.
- Trowler, V. (2010). *Student engagement literature review*. The Higher Education Academy.
- Ugwoke, E. O., Olulowo, T. G., & Adedayo, I. O. (2020). Using guided discovery to improve students' retention and academic attitudes to financial accounting concepts. *Education Research International*, 6690082. <https://doi.org/10.1155/2020/6690082>
- van Hiele, P. M. (1986). *Structure and insight: A theory of mathematics education*. Academic Press.
- Vojkuvkova, I. (2012). The van Hiele model of geometric thinking. In *WDS'12 Proceedings of Contributed Papers*, Prague (pp. 72–75).
- Wang, M.-T., Fredricks, J. A., Ye, F., Hofkens, T. L., & Linn, J. S. (2016). The math and science engagement scales: Scale development, validation, and psychometric properties. *Learning and Instruction*, 43, 16–26. <https://doi.org/10.1016/j.learninstruc.2016.01.008>
- Wang, Y., & Tambi, F. B. (2024). Correlation between students perceived parental expectations and students academic engagement: The intermediary effect of academic self-efficacy. *Journal of Pedagogical Research*, 8(3), 16–33. <https://doi.org/10.33902/jpr.202427683>
- White, H., & Sabarwal, S. (2014). Quasi-experimental design and methods. *Methodological Briefs: Impact Evaluation* 8, 8, 1–16.
- Zakaria, Z. (2010). The effects of cooperative learning on students' mathematics achievement and attitude towards mathematics. *Journal of Social Sciences*, 6(2), 272–275. <https://doi.org/10.3844/jssp.2010.272.275>
- Zhang, D. (2017). Effects of visual working memory training and direct instruction on geometry problem solving in students with geometry difficulties. *Learning Disabilities: A Contemporary Journal*, 15(1), 117–138.

Week 5	6.3. More on circle <ul style="list-style-type: none">✓ Definition of a circle<ul style="list-style-type: none">➤ Parts of a circle➤ Line segment on a circle✓ Relation between circle and straight line✓ Angle on a circle	✓ VHGGDIA for Experimental Group ✓ CTM for Comparison Group
Week 6	✓ Activities related to circle 6.4. Regular polygon <ul style="list-style-type: none">✓ Define a polygon<ul style="list-style-type: none">➤ Classification of a polygon✓ Regular polygon<ul style="list-style-type: none">➤ Basic terms on a regular polygon➤ Length of sides of a regular polygon➤ Perimeter of a regular polygon➤ Area of a regular polygon	✓ VHGGDIA for Experimental Group ✓ CTM for Comparison Group
Week 7	✓ Activities related to regular polygon <ul style="list-style-type: none">✓ Project work (Draw a real-life problem that readily solved using two or more plane geometry concepts learned in the classroom)	
Week 8	Post-intervention data collection through (posttest and teacher Interview)	