



The Effect of Inquiry-based Learning on Senior High School Students' Achievement in Plane Geometry: Pre-test-Post-test Randomized Experimental Design

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Using inquiry-based learning, this study investigates high school students' achievement in plane geometry. It employed the pre-test-post-test randomized experimental design, often known as the control group design. The participants (students) were randomly assigned to one of two classes/groups and were given either an intervention (the treatment group) or no intervention (the control group). One hundred and twenty (120) third-year high school students of similar mathematical aptitude (a control group = 60 students; an experimental group = 60 students) were chosen from a high school in Ghana's central region. Shapiro-Wilk had a p-value greater than .05 ($p > .05$) for each statistic, indicating that both the pre-test and post-test scores were normally distributed, before and after the test. The findings of the independent samples t-test showed that there was no statistically significant difference between the experimental and control pre-test scores ($t = -.48, p > .05, C. I = [-1.78, 1.08]$). The one-way ANOVA after inquiry-based learning showed a significant effect on student scores, $F(1, 118) = 363.41, p < .05$. Furthermore, independent samples t-test findings for the post-test showed statistically significant differences between the experimental and control post-test scores ($t = -22.68, p < .05, C. I = [-24.29, 20.40]$). The study's implications are that students can make their own connections with the content they learn. They may also comprehend the themes rather than simply recalling rules and formulas. The study concludes that inquiry-based learning improves senior high school students' achievement in plane geometry.

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Keywords: Plane geometry; pre-test-post-test randomized experimental design; an inquiry-based learning method; randomized classes.

1 Introduction

Due to its relevance in education and people's lives, many researchers are enthusiastic about studying mathematical achievement [1,2]. Mathematical understanding and skill are unquestionably important for students' achievement [3], and mathematical achievement is related to people's well-being, satisfaction, and employability [4]. For students to understand their teachers, they must apply different instructional strategies in the classroom. They must select these instructional strategies according to the content they present. Mathematics instruction has transitioned from traditional teacher-centred methods to interactive and student-centred ones [5]. However, the efficacy of student-centred techniques for mathematics achievement poses numerous concerns [6]. Some studies have looked into the impact of teaching approaches on students' academic achievement [7,8], with the majority of the findings indicating that students do badly due to insufficient instructional practices [8]. Students benefit from engaging in numerous mathematical tasks when employing inquiry-based learning in mathematics. Their mathematical creativity improves as a result of effective problem-solving, problem-posing, and modeling of mathematical activities, which are the foundations of inquiry-based instruction. In contrast to other learning approaches, inquiry-based learning allows students to develop and participate in mathematical tasks in order to explain, discuss, and reflect on their ideas [8].

2 Literature Review

Some scholars have questioned the significance of emotional or motivational factors [9]. [10] recently concluded that mathematical desire and fun are major predictors of mathematical achievement. Similarly, [4] discovered that IQ and attitudes toward mathematics were important predictors of mathematics achievement. However, students' abilities and talents did not entirely explain the amount or nature of mathematics achievement [11].

Students' perceptions of themselves as learners, as well as their ability to finish mathematics assignments successfully, are essential sources of motivation for them [10]. The perceived utility of mathematics is sometimes defined as students' understanding of the relevance and importance of learning in their lives [12]. Higher mathematical achievement may result from the relationship between the importance of a subject and the ability to learn new concepts [13]. Strong student motivation boosts mathematical tasks as well as actual and cognitive capacities, which improves deep learning [14]. The relationship between academic motivation and math achievement has received a lot of attention [15,16].

Motivated students are more likely to seek out learning opportunities and surpass their peers in mathematics [17]. Students benefit from the ability to discriminate between accomplishment motivation and the tendency to achieve predetermined goals [18]. Furthermore, intrinsic drive, or the desire to improve one's task expertise, is tremendously beneficial [19,20]. Although both types of motivation are connected with perceived mathematical ability, intrinsic motivation is associated with higher rates of mathematical achievement and success [10,17]. Students' motivation to learn is inextricably linked to how they respond to academic successes and failures [19].

Students' motivation and academic development are affected by causal attributions, which are what people attribute to their successes and failures [20]. According to research, the more adaptive attributional patterns there are, the more successful the school is [9,21]. When learning mathematics challenges, anxiety and other emotional reactions are prevalent [22]. Mathematics anxiety is a negative attitude toward mathematics that leads to avoidance of math classes and low arithmetic skills and achievements [23].

In terms of age disparities, both transversal and longitudinal studies have consistently shown that mathematics performance falls throughout adolescence [24,25,26]. Furthermore, studies have demonstrated that mathematical motivational and emotional features change with time, with perceived competence, perceived usefulness, intrinsic drive, and anxiety decreasing as children move through school [27,28,29].

People of all ages and backgrounds employ learning strategies [30,31], ranging from simple methods used for mathematics [32,33] to advanced approaches used for problem-solving and reasoning [34,35]. The correlations

between various learning approaches and mathematics literacy have revealed that one of the most important aspects leading to mathematical achievement is selecting an efficient problem-solving style. According to [36], acquiring meta-cognitive skills such as control and elaboration methods is just as crucial as mastering computational skills. Students' mathematics achievements improve when they apply elaboration tactics frequently [37,32,38].

Teachers' mathematical knowledge and views are influenced by their teaching choices [39,40,41,42,43,44]. These teachers must have extensive expertise in order to appropriately educate different students for challenging work in schools [45]. They must not only have an understanding of a specific subject, but they must also have solid pedagogical knowledge [46]. Their proficiency in these areas is intimately related to students' mathematical thinking, knowledge, and learning. Student achievement in mathematics necessitates teachers who are well-versed in the topic [47,48,49]. Consequently, grounded on data from previous research, the following question was set: Are there statistically significant differences in scores between the post-test and pre-test in students' achievement in plane geometry after using the inquiry-based learning method, as an intervention?

3 Materials and Methods

3.1 Design

The pre-test-post-test randomised experimental design, also known as the pre-test-post-test control group design, was employed in the investigation. Participants (students) were randomly allocated to either an experimental or a control group for this design. Students in the experimental group were taught using inquiry-based learning, while those in the control group were taught using the conventional method. The pre-test was administered before the experimental group was taught using inquiry-based learning, and the post-test was administered thereafter. The goal was to assess the impact of inquiry-based learning on the students' achievement in plane geometry. This design featured three primary features: The students were randomly assigned to either the experimental or control groups (this was done before the experiment). Except for the inquiry-based learning, all groups were subjected to the same conditions: The experimental group received the intervention, while the control group did not. Both groups' achievement levels were measured concurrently at two points: the pre-test and the post-test. Fig. 1 shows the pre-test-post-test randomised experimental design.

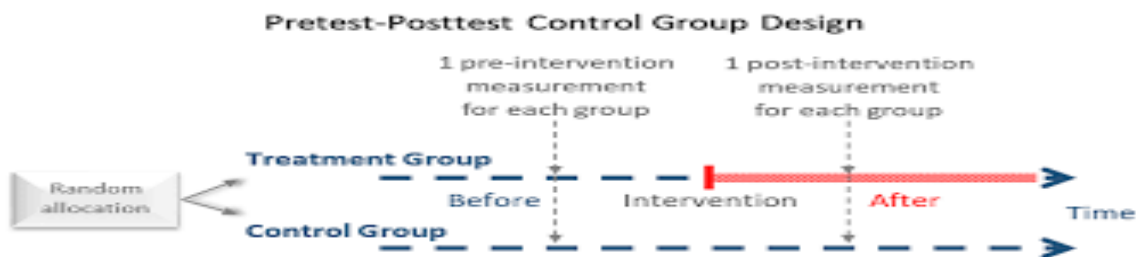


Fig. 1. Pre-test-post-test randomized experimental design

3.2 Participants

The participants were one hundred and twenty (120) third-year senior high school students of equal ability achievement in mathematics, who were randomly assigned into two groups (a control group = 60 students; an experimental group = 60 students), and selected from a high school in the central region of Ghana. The four hundred and thirty (430) third-year students in the school, came from all sixteen regions of the country, with an average age of eighteen years, and two months.

3.3 Intervention

Inquiry-based learning, a student-centered active learning strategy, emphasises questioning, critical thinking, and problem-solving. It is frequently used in mathematics to enhance student learning [50]. It promotes a hands-

on approach to learning in which students apply mathematical concepts to real-world issues. It all starts when teachers assign students tasks to solve [51]. Students learn to discover and collect appropriate evidence, present outcomes methodically, analyse, and interpret results during these times [52].

Teachers of mathematics create scenarios in which students discover the power of ideas and construct conceptions of authentic activities. Inquiry-based learning allows students to research an issue or problem by collecting and analysing data. Teachers help students navigate their challenges by guiding them. According to [50], teachers who utilise the inquiry-based method plan lessons that help students develop problem-solving and critical-thinking skills. Teachers establish a problem for research and ensure that students have access to the necessary resources to answer the problem in order to build these inquiry-based abilities in their pupils.

To boost interest and participation, teachers must allow students the opportunity to analyse and solve problems [52]. The goal of inquiry-based learning is to encourage independent thought. Involving students in the inquiry approach aids in the development of higher-order critical thinking skills such as explanation and research [53].

3.4 Pre-test and post-test

The pre-test had forty (40) questions covering the whole plane geometry topics. Before introducing inquiry-based learning, these questions were given to the students to assess their knowledge of plane geometry. Similarly, the post-test included forty (40) questions that were not on the pre-test. However, the focus was similar to that of the pre-test. The post-test was given to the students after they had been introduced to inquiry-based learning. It took four hours to finish the inquiry-based learning.

4 RESULTS

Table 1. Tests of normality for the pre-test and post-test

	Group	Statistic	Shapiro-Wilk	
			df	Sig.
Pre-test	Control	.97	60	.12
	Experimental	.96	60	.21
Post-test	Control	.98	60	.14
	Experimental	.95	60	.23

Table 1 shows the tests of normality for pre-test and post-test scores. For pre-test and post-test scores, Shapiro-Wilk has a p-value greater than .05 ($p > .05$) for each statistic, indicating that both the pre-test and post-test scores were normally distributed. Table 2 shows the independent samples t-test for pre-test scores.

Table 2 shows the independent samples t-test for pre-test scores. Levene's test for equality of variances shows that the equal variance assumption is upheld ($F = .02, p > .05$). The results of the independent samples t-test indicated a non-statistically significant difference between the experimental and control pre-test scores ($t(118) = -.48, p > .05, C. I = [-1.78, 1.08]$). Table 3 shows the ANOVA table of tests of between-subjects effects with their difference as the dependent variable.

Table 3 shows the tests of between-subjects effects between the experimental and control groups. A one-way ANOVA indicated that the effect of the method of instruction was significant for student scores, $F(1, 118) = 643.41, p < .05$. The group statistics indicated that the experimental group ($M = 24.87, SD = 6.70$) performed better than the control group ($M = 1.42, SD = 1.95$). Table 4 indicates the paired-sample t-test for pre-test and post-test scores.

Table 4 shows the paired-sample t-test for pre-test and post-test scores. The results indicated that the pupils' post-test scores were statistically higher than their pre-test scores ($t(119) = -11.24, p < .05$), this follows from the difference between the post-test and pre-test means of -13.14. Table 5 shows the independent samples t-test for post-test scores.

Table 2. Independent samples t-test for pre-test scores.

		Levene's test for equality of variances		t-test for equality of means					95% C.I.	
		F	Sig.	t	df	Sig. (2 tailed)	Mean difference	Std. error	Lower	Upper
Pre-test	Equal variances assumed	.02	.90	-.48	118	.63	-.35	.72	-1.78	1.08
	Equal variances not assumed			-.49	117.99	.63	-.35	.72	-1.78	1.08

Table 3. The ANOVA table of tests of between-subjects effects with their difference as the dependent variable

Source	Sum of Squares	Degrees of Freedom	Mean Square	F	Sig.
Group	16497.08	1	16497.08	643.41	.000
Error	3025.52	118	25.64		
Total	19522.59	119			

Table 4. Paired samples t-test for the pre-test and post-test scores

				95% C.I.		t	df	Sig. (1 tailed)
	Mean	Std Deviation	Std. Error Mean	Lower	Upper			
Pre-test-Post-test	-13.14	12.80	1.17	-15.46	-10.83	-11.24	119	.000

Table 5. The independent samples t-test for post-test scores

		Levene's test for equality of variances		t-test for equality of means					95% C.I.	
		F	Sig.	t	df	Sig. (2 tailed)	Mean difference	Std. error	Lower	Upper
Post-test	Equal variances assumed	17.68	.00	-24.23	118	.00	-23.80	.98	-25.75	-21.86
	Equal variances not assumed			-24.33	104.70	.00	-23.80	.98	-25.75	-21.86

Table 5 shows the independent samples t-test for post-test scores. Levene's test for equality of variances shows that the equal variance assumption is violated ($F = 17.68, p < .05$), hence equal variances are not assumed. The results of the independent samples t-test indicated statistically significant differences between the experimental and control pre-test scores ($t(98) = -24.33, p < .05, C. I = [-25.75, -21.86]$). Fig. 2 shows the estimated marginal means of the difference between post-test and pre-test scores.

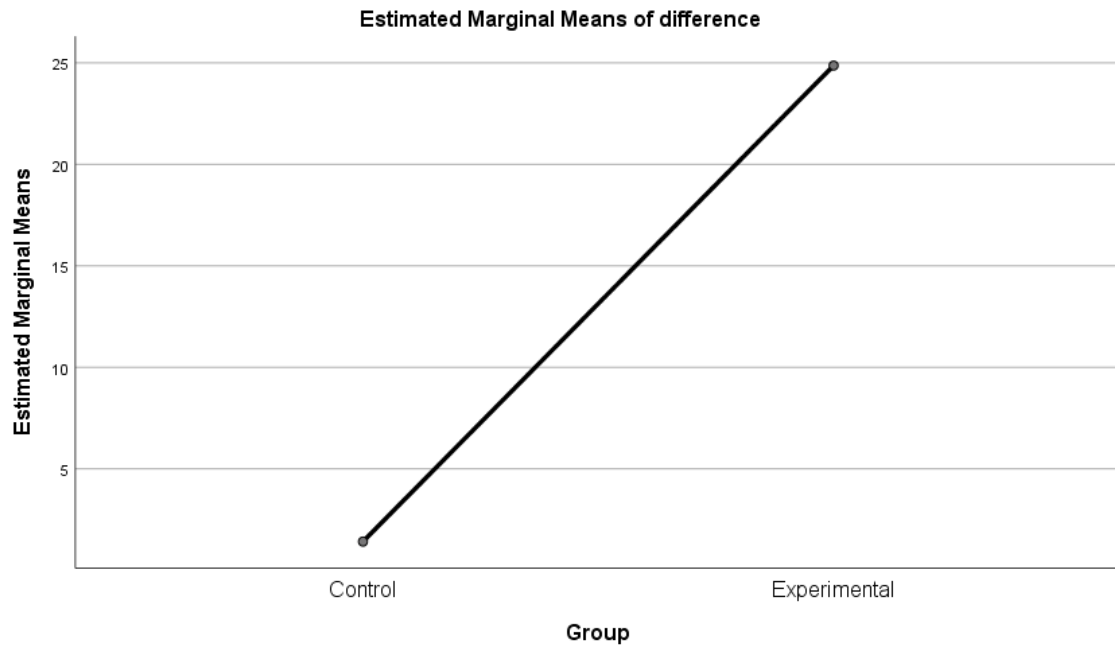


Fig. 2. Estimated marginal means of the difference between the post-test and pre-test scores

Fig. 2 shows the estimated marginal means of the difference between the post-test and pre-test scores. The figure indicated that the estimated marginal mean for the experimental group ($M = 24.87$), was higher than the mean of the control group ($M = 1.42$).

5 Discussion

Inquiry-based learning begins when teachers give their students questions to answer, issues to resolve, or observations to explain [51]. Students become motivated and encouraged to formulate questions and draw meaningful conclusions [52]. Inquiry-based learning is seen to include other inductive learning methods and is associated with interactive learning, discussions, and simulations [54]. Inquiry-based learning allows students to seek a thorough understanding of mathematics processes, thereby affecting human civilisation. Every student can uniquely create new ideas, which are often seen as a personal adventure peculiar to every student. Teachers can help to create situations for students to discover new ideas and concepts themselves. They can assist their students to arrive at the correct solutions. Under inquiry-based learning, teachers develop lessons that enable students to recognise problems and gather relevant facts to critically assess the solutions [50].

Inquiry-based learning is often associated with some specific skills which develop among students when teachers use this technique. Teachers must be able to facilitate the process of students' demonstration of curiosity and enthusiasm in inquiry lessons. Teachers must design problems for students to investigate and ensure that they have access to the requisite data to solve the problem. Students should also be able to connect their past experiences and knowledge, through adequate planning and thinking, to increase their classroom participation [52]. Inquiry-based learning stimulates or promotes independent thinking. When students are involved in classroom activities, it enables them to develop their critical thinking skills [53].

In inquiry-based learning, students' experiences sometimes occur outside the classroom. In mathematics, students display skills and attitudes that allow them to find solutions while constructing new knowledge.

Inquiry-based learning motivates students to explore the content and associated issues of a concept. Teachers must design activities and assignments in inquiry-based learning to enable students to work individually or together to solve problems. Even though inquiry-based learning is largely student-centred, teachers must vary the extent to which student-directed learning can play a central role in the learning process. In other jurisdictions around the world, teachers employ control strategies when teaching their students how to solve problems [55]. [56] explain that students would be more knowledgeable if teachers ask questions that promote students' thinking. In this regard, students review prior knowledge and make a connection to new knowledge to reinforce their understanding of new ones.

Stereotypes about mathematical ability and traditional norms may fade into the background in classes where students actively participate with their peers in the research and discovery of relevant themes and issues [57,58]. Inquiry-based learning may give a critical opportunity to less cognitively endowed students to belong to the mathematics community since it encourages them to take greater ownership and agency in the classroom [59].

The training teachers receive has a direct association with their preparation and confidence in teaching inquiry-based learning. Those who have received further training are more at ease with inquiry-based learning. Open-ended learning environments are especially difficult for teachers who have little training or experience with inquiry-based learning [60]. Teacher preparation programmes contribute positively to the development of pedagogical perspectives toward inquiry-based teaching among teachers [61].

Teachers' perspectives and teaching styles are critical to the successful implementation of any learning model. Due to a lack of pedagogical knowledge and understanding of inquiry-based learning, teachers frequently skip it [62]. Such teachers are expected to go to great lengths to properly teach their students the new knowledge they gain through inquiry-based learning. For every student to participate actively in classroom discussions, these teachers require longer instruction time than the standard instruction time. Despite the fact that inquiry learning is student-centered, teachers are responsible for setting all of the limits of inquiry-based learning in order for students to participate in the classrooms [63].

6 Implications to Teaching and Learning

In mathematics learning, people's abilities and attitudes complicate the inquiry that allows students to solve problems by constructing new knowledge. In inquiry-based learning, teachers must provide activities and assignments for students to address problems individually or together. Teachers should adjust the degree of student-centeredness in inquiry-based learning at their discretion, based on students' cognitive levels and comprehension of the inquiry process. Inquiry-based learning in mathematics allows teachers to actively engage students in mathematics debates. Teachers help students acquire geometric ideas through inquiry-based learning by letting them examine an issue and generate possible solutions, providing students with more opportunities to reflect on their techniques in order to gain a deeper comprehension of the topic and concepts. Inquiry-based learning boosts student motivation and is an excellent way to engage students actively in mathematics learning. Inquiry-based learning enables instructors to assist students in learning content and concepts by allowing them to investigate a problem and generate acceptable answers.

7 Conclusions

Inquiry-based learning has the ability to foster student interests, passions, and abilities in the mathematics classroom. It can boost student motivation and engagement while also cultivating their curiosity and love of learning. It can instill tenacity, perseverance, a growth attitude, and self-control among students. It can help them improve their formal and casual research skills. Beyond the topic, inquiry-based learning can help students to improve comprehension. It can reinforce the significance of asking smart questions. It necessitates that students participate actively in the learning process, and this can assist solve tomorrow's challenges in today's mathematics classrooms.

Inquiry-based learning is essential for mathematics learning because conventional lecture-based learning does not deliver the appropriate level of success. Furthermore, memorization-based mathematics learning has failed to develop workforce-ready workers [64]. Through inquiry-based learning, the constructed new information by developing explanations from evidence and connecting explanations to existing knowledge [65]. The inquiry

learning cycle should incorporate knowledge exchange and lifelong learning rather than just new knowledge construction [66]. Teaching tactics that actively engage students in the learning process through scientific investigations are more likely to improve conceptual knowledge than passive learning strategies [67].

Competing Interests

Authors have declared that no competing interests exist.

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