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Effectiveness of Instruction with Manipulative Materials on Fourth Graders' Geometry Learning Achievement

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Abstract

The concepts of geometrical figures, shape, and size are essential for learning their features, relations, and proofs. In the geometry classroom, a good teacher is expected to use the objects related to geometrical shapes for the real concept and knowledge of the figures, and to improve the learning achievement of young learners. In this context, this study aimed to compare the learning achievements obtained from using and without using manipulative materials in teaching geometry, especially in grade four, and identify students' general attitudes and feelings towards the instruction with the demonstration of the concrete objects. For this purpose, the researcher employed the Basic Experimental and Post-test Only Control Group Design to form two groups, the Experimental Group and the Control Group, having a similar level of prior knowledge and competence in geometry. Each group consisted of 13 students studying in grade four at Kapiya Secondary School, Khairahani, Chitwan, Nepal. The same achievement test was conducted for both groups after a month's intervention. The t-test was used to draw the significant deviation between the achievements. The result showed that the mean achievement of the learners who were instructed through manipulative objects was better than the achievement of the learners instructed without using them. After the test, some students from the Experimental Group were chosen for the interview to uncover their perceptions before and after the intervention. It revealed that students enjoyed the class based on learning with the manipulation of concrete objects. The study guides the mathematics teachers teaching junior classes to involve the students in the manipulation of different types of materials in geometry activities for the real concept of geometry and enhancement of learning achievement.

Keywords*:* experimental group, intervention, manipulative, posttest, t-test

Introduction

Mathematical knowledge and skills help the students identify the sources and materials to be used in the proper situations in real life. They play a vital role in the development of logical conclusions and critical thinking in the context of scientific investigation,

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research, information, and technology. It is valuable to adjust to development and new changes in knowledge, science, and technology in the development of a technology-friendly society along with the changeable context. Different countries have their own goals and objectives for mathematics in nation-wise, level-wise, gradewise frameworks. Based on the nation's need for availability and access to their source and materials, they have organized the content to fulfill their national goals and objectives. Among different subject contents, mathematics is one of the vital and most valuable subjects in the school-level curriculum (Curriculum Development Center, 2077).

In the context of Nepal, mathematics is taught as a compulsory subject with full credit hours from grades 1 to 10. In the curriculum of grade four mathematics, the contents related to Geometry, Arithmetic, Measurements, Statistics, and Algebra are included. Level-wise competencies, grade-wise learning achievements, scope and sequence, teaching-learning process, and evaluation process, are mentioned in the curriculum. Weekly 5 and yearly 160 teaching hours have been assigned to the teaching-learning process. This curriculum emphasizes the behavioral and practical part based on the theory of "learning by doing" related to real life. The contents of Geometry have been placed at the beginning. The course focuses on the topics 'line and angles' and 'shapes of solid objects in grades 4 and 5. Experimental methods, research and discovery methods, discussion and question-answer methods, and inductive methods are emphasized in teaching geometry at the basic level.

In the context of the learning hierarchy of geometry learning, The Van Hiele theory (1990, 1996, and 1999) proposes 5 levels of geometrical thinking sequentially, with the lowest level being the visual level, named holistic thinking. Different numbering systems are found in the literature, but Van Hieles spoke of levels ranging from 0 to 4: Level 0 (Holistic Thinking), Level 1 (Analytic Thinking), Level 2 (Abstract Thinking), Level 3 (Deductive Thinking), and Level 4 (Rigorous Thinking). At Level 0 (Holistic Thinking), the students recognize basic geometric concepts through visual presentation of the concept as a whole without regard to the properties of its components (Villiers, 1996). At Level 1 (Analytic Thinking), students recognize the properties of figures, but they are not yet logically ordered (Van Hiele, 1999). Similarly, at Level 2 (Abstract Thinking), students logically relate previously discovered properties or rules with the help of informal arguments such as object representation through drawings, illustrations, etc. (Feza & Webb, 2005). At level 3 (Deductive Thinking), properties are logically ordered and deduced from one another. Learners use already known properties to formulate definitions despite not understanding the intrinsic meaning of deduction (the role of axioms, definitions, and theorems) (Mayberry, 1983). Finally, at Level 4 (Rigorous Thinking), the student can work in different geometric or axiomatic systems and would most likely be enrolled in tertiary education in geometry (Teppo, 1991; Pegg, 1995 as cited in Decano, 2017). Van Hiele's (1990) theory focuses on level 1 thinking for the manipulation of objects in the geometry learning process of fourth-grade students.

Similarly, Piaget (1973, as cited in Ojose, 2008) studied the stages of cognitive development of children from birth to maturity. His theory identified four developmental stages (sensory motor stage, preoperational stage, concrete operations, and formal operations) and the processes by which children progress through them. According to Piaget's theory, every next stage depends on the completion of the previous stage, and the development is going on the stages sequentialy. Both Piaget (1973) and Dienes (1971) were concerned with providing active student involvement through the use of a huge amount of concrete materials in the learning process.

Bruner (1966) also supported Piaget's theory. He described three ways of knowing: enactive, iconic, and symbolic. He stated that the learner experiences the features of the objects by touching, smelling, and tasting then. Later, he/she developed and drew a mental sketch of the objects. Even later he/she connected names with the objects. According to Bruner, after children learn to distinguish objects by color, size, and shape, they begin counting numbers. The main focus related to this study, according to Bruner, is when children start school, their education needs to start from concrete to abstract. Manipulatives can assist in this transition from concrete to abstract (Howden, 1986; Thompson, 1994; Moyer, 2001; McClung, 1998; Suydam & Higgins, 1976 as cited in Sari, 2010). Brown (2006) claimed that manipulatives were very important tools to make the connection from abstract to concrete understanding in everyday situations.

Along with other factors, including knowledge and attitudes, teachers can select classroom strategies based on their beliefs (Van der Sandt, 2007). Beliefs play an important role in the decisions pre-service teachers make regarding their choice of teaching experiences. These decisions in-service and pre-service teachers make about their practice are influenced by then their beliefs about models of teaching mathematics (Ernest, 1989). Along with this, Buehl and Beck (2014) have suggested that their beliefs are influenced by teachers' practice, not only by beliefs. Teacher practice involves finding strategies to help students understand the underlying concepts of abstract mathematical ideas. This can be a challenge for some primary teachers, and they are encouraged to employ a variety of strategies to enhance the learning of their students (Carpenter et al., 1996). One particular strategy recognized as a potential benefit for the student's understanding of mathematics is the use of concrete materials to represent mathematical ideas (Moyer, 2001). The, National Council of Teachers of Mathematics

(NCTM) has also recommended using concrete materials to represent mathematical ideas in their principles and standards for school mathematics (2000). Although there have been some vague and negative results, various studies have demonstrated that the use of concrete materials in the classroom may be more successful than using abstract symbols alone, and may assist in developing a real understanding of mathematical concepts, particularly when used in conjunction with appropriate classroom strategies (Carbonneau et al., 2013; Sarama & Clements, 2016; Thompson, 1994).

Here, the term ‘concrete materials’ is used synonymously with the term 'mathematical manipulative' throughout the mathematics education literature. This study focuses on physical or concrete manipulatives used in teaching geometry. They can be specifically designed for use in mathematics classrooms, such as different solid shapes (cubes, cuboids, cylinders, cones, etc.), different shapes by using geoboard in geometry, counters, base 10 blocks, or Cuisenaire rods in arithmetic and algebra. Moreover, the broader meaning of concrete materials may include objects such as toys or dolls (McNeil &Jarvin, 2007). Moyer (2001) defines concrete objects as those used by students to conceptualize an abstract mathematical idea. Students should be able to touch and hold concrete materials and move them around (Moyer, 2001), and use them to "experiment and explore" (Demetriou, 2015, p. 1912). In more recent times, the use of concrete materials has been advanced by government education authorities both within Australia as well as internationally. For example, the United States of America's Common Core Standards for Mathematics promote their use for modeling in problem-solving (Common Core State Standards Initiative, 2020). The Singapore ministry has suggested the teachers of grades One to Six for using concrete materials for the promotion of the discovery and understanding of abstract mathematical concepts (Ministry of Education Singapore, 2012). The Australian Curriculum: Mathematics (2020) suggests that students should use concrete materials to build patterns and models, while in the New South Wales (NSW) Syllabus for the Australian Curriculum: Mathematics K–10 Syllabus (NESA, 2019), concrete materials in the teaching-learning process are mentioned as a means of modeling mathematical concepts from Early Stage 1 (Foundation/Kindergarten) through to Stage 4 (Grades 7 and 8). So, many countries' national curricula advocate the incorporation of concrete materials into learning and teaching experiences. Further support for the incorporation of concrete materials can be found in constructivism.

Some general concepts, points, lines, planes, surfaces, angles, and curves, as well as the more advanced notions of manifolds and topology or metrics concepts, are more or less fundamental to geometry, and are practiced by different ethnic groups too. (Bhushal, 2010). In Nepal, there are several ethnic groups with their typical traditions and practices. The different ethnic groups have their geometrical concepts. They use their geometrical knowledge, concepts, and processes in their daily life knowingly or unknowingly. They use different geometrical concepts in their perception. In Kapiya community of Chitwan, Nepal, there are specially Tharu and Darai ethnic groups. In this experiment, most of the students have been sampled from Darai and Tharu communities.

Several studies (Carbonneau et al., 2013, Amatya, 1978; Jaisi, 2020; Demertiou, Louiza, 2015; Sowell, 1989) have been conducted on the issues of the use of concrete materials in the regular class. However, very few studies have been carried out on the effectiveness of concrete materials on primary level students' geometry learning achievement and attitude in the context of Nepalese young learners. Thus, this study aims to bridge this gap by identifying the effectiveness of this instruction with concrete objects on the geometry learning achievement and attitude of the students, especially in the class with the majority of Darai and Tharu students. The main research question for this study is: Does the instruction with concrete materials increase the fourth-grade students' geometrical achievement of the learners? Also, this study focuses on the perceptions of Darai and Tharu students about instruction with concrete materials.

Research Hypothesis:

Null hypothesis (H_0): There is no significant difference in fourth-grade students' achievement in geometry in two groups after instruction using and without using concrete materials

Alternative Hypothesis (H_1): The instruction using concrete materials increases the learning achievement of the students.

Review of Literature

Several empirical studies have explored the issues of the effectiveness of concrete materials in classroom teaching in the global and Nepalese context. They have dealt with the use of a variety of concrete resources in mathematics education to scaffold the children to understand the geometrical concepts. Some key research findings in the global and Nepalese contexts have been reviewed in this section respectively.

Sari (2010) researched 'The Effect of Instruction with Concrete Materials on Fourth-grade Students' Geometry Achievement" in the context of Turkey. The results of his study revealed that there was a statistically significant change in geometry achievement of fourth-grade students who participated in the instruction with concrete materials over three time periods. In other words, there were statistically significant positive changes in students' geometry achievement across different courses of treatment. Moreover, there was no statistically significant change in students' achievement across post-intervention and follow-up. He concluded that most of the students enjoyed the class more when concrete materials were used. Some of the students became anxious when they first saw the questions before intervention. Most of the students stated that questions become easier after instruction with concrete materials.

Othaman, et al. (2017) in their study "The Use of Concrete Materials in Teaching and Learning Mathematics" claimed that the use of teaching aids (concrete materials) was very important in every introduction to the concepts of mathematics in primary schools. The analysis of the data showed that the teachers had played a proactive role in educating the students and developing an understanding of mathematics. Similarly, Quigley (2020) in his study entitled "Concrete Materials in Primary Classrooms: Teachers' Beliefs and Practices" claimed that teachers' beliefs and practices significantly impact why concrete materials are used in the mathematics classroom. They could be used to help children think, make a concept visible, engage learners, help them to move from concrete to abstract thinking, focus the conversation, and articulate ideas or for reinforcement and consolidation. Furthermore, teachers' beliefs and practices considerably affect how concrete materials are used in the mathematics classroom. They might be used to demonstrate or explore a concept, build patterns, or play games.

Sarı and Aydoğdu (2020) in their research "The Effect of Concrete and Technology-assisted Learning Tools on Place Value Concept, Achievement in Mathematics and Arithmetic Performance" concluded that the effect of both concrete and technology-assisted learning tools on developing the place value perception of primary school 4th-grade students was significantly high when compared with students who did not use any such learning tools. In other words, materials prepared with the purpose of developing place value concept, concrete (Dienes blocks, snap cubes) and technology-assisted (place value materials) learning tools were more effective in developing the place value conception of students.

In the context of Nepal, using concrete materials in geometry teaching is an appropriate way to conceptualize geometrical shape and size. There is no high access to economy, science, and technology in the people of Nepal. So, the construction of low and no-cost materials from our periphery in society is the proper way to demonstrate geometry instruction. It certainly increases the achievement of primary-level students. In this regard, Bhusal (2010), in his study, "A Study on the Use of Geometrical Concepts by Darai Community: an Ethnomathematics Study of Chitwan district" concluded that Darai people have been mainly using geometrical concepts/conventions like the circle, sphere, semi-sphere, cone, cylinder, parallelism, perpendicularity, and different angle, etc to construct different objects. Increasing needs and rapid development of technology have forced people to learn modern geometrical concepts. He forced Darai people to learn formal geometrical concepts.

Jaisi (2020) in his study entitled “Effectiveness of Manipulative Materials in Teaching Mathematics” concluded that students taught using manipulative materials performed significantly better compared to the control group. He focused on the effectiveness of using manipulative materials depending on students' understanding of abstract concepts. The study revealed that appropriate use of manipulatives is essential for comprehensive mathematics instruction. His experimental research showed that the students who were taught by using the material were more active, and had regular participation in all activities of the classroom in comparison to others.

Besides this, the prior studies have not sufficiently explored the variation in the achievements of different groups of students with reference to their caste and gender. The literature review enabled the researcher to find out the significant deviation between the achievements of the group of students with and without using manipulative materials in geometry teaching along with their perception of manipulation of concrete materials as well.

Methodology

This research was based on the Basic Experimental and Only Post-test Control Group Design. For this purpose, the researcher formed two groups, the Experimental Group and the control group having a similar level of existing knowledge and competence in geometry from the class to observe and measure the effectiveness of concrete objects on the learning achievements and attitudes of the 4th graders. The Geometry Achievement Test (GAT) was administered after the intervention. The following table shows the research design of this study.

Table 1: Research Design

Group Division	Treatment	Measuring Instrument 1	Measuring Instrument 2
Control Group	Instruction without using concrete objects and materials (pictorial representation only)	Geometry Achievement Test (out of full mark 50)	
Experimental Group	Instruction using concrete objects and materials, Observation of participation and classroom activities during the instruction time	Geometry Achievement Test (out of full mark 50)	Interview with selected students from the Experimental Group

First, the researcher closely examined and analyzed the prior learning achievements 26 students of the learners reflected in their recent class tests and terminal exams to identify the existing level of the learners. Then, they were categorized into two groups each having 13 students: the Control and the Experimental Group, based on the ratio of the existing level of achievement. The Control group was instructed to draw pictorial representations of geometrical figures, shapes, and solids without the use of concrete materials. And the Experimental Group was instructed with the manipulation of concrete materials. The participation of the Experimental Group in the manipulation of the materials was observed during the instruction time. Each group was engaged in teaching-learning activities for about one hour regularly. After 20 days' completion of geometry teaching, the GAT (Geometry Achievement Test) was administered to both groups. Their obtained marks were recorded for analysis. After completing the test procedure, 8 students from the Experimental Group were selected for an interview.

This study took place in Kapiya Secondary School, Khairahani, Chitwan in the academic year 2021-22. Both groups were taught the same mathematical content from the same textbook throughout the month: one group using concrete materials and the other without using concrete materials. The gender and caste distribution for the study sample was almost equal. The following table shows information about the total number of students and the number of girls and boys with their caste in the two groups.

Table 2: Caste-wise Distribution of Students

Groups	Number of Boys		Number of Girls	
	Janajatis	Others	Janajatis	Others
Control Group	3	2	4	4
Experimental Group	4	2	5	2

The measuring instruments GAT, Interview schedule and t-score were administered after treatment and data collection. Only one Geometry Achievement Test (GAT) was developed to determine the students' geometry achievement. After the intervention table of specifications and evaluation process in the curriculum were studied for the content validity of the GAT. The questions were classified according to basic geometrical concepts.

For collecting the students' views and opinions about the instructions on concrete materials, an interview was conducted as a data collection method. Before the interview, the students were reminded of the materials which were used during the treatment. Those concrete materials were cubes, cuboids, mason rulers, geoboard, pattern blocks, symmetry mirrors, straw, tangram and geometry strips. The interview included questions related to opinions and feelings about instructions with concrete materials. Students' answers were categorized as "enjoyment", "anxiety", "easiness",

The purposes of the interview questions are given in the table below:

Table 3: Interview schedule

Interview Questions	Purpose
What comes to your mind when you think about Mathematics?	To identity their impression of Mathematics
What were your feelings (ease or difficulty) before your teacher taught you geometry using concrete materials?	To examine the students' feelings about teaching without the use of concrete materials.
How did you feel (ease or difficulty) about the questions during and after your teacher taught you geometry by using concrete materials?	To examine the students' feelings during and after using concrete materials.
Do the activities with the use of concrete objects improve your understanding of geometry during your study of that concept?	To reveal the perception of students regarding activities, their understanding and emotional feelings about this question.
How do you feel while using concrete materials? Why?	To investigate the emotional feelings while using concrete materials and the reasons.

Results and Discussion

First, descriptive statistics was used to classify and summarize numerical data. The following table shows the different statistical values related to the data obtained from GAT

Table 4: Analysis I

Test of siginificant difference between the average achievement of two groups

Group	Number of participants	Sum of Scores	Sum of Squares of Scores	Average Score	Maximum Score	Minimum Score
Experimental	13	326	8778	25.07	42	10
Control	13	257	5589	19.77	33	8

Simply, the effect of the treatment can be seen from the above calculation. The mean achievement of the Experimental Group is higher than the Control Group. But the range of the scores between the higher and lower scores has not decreased. The distribution of the achievement still has variations. Second, the main research question of the study "Does the instruction with concrete materials increase the fourth-grade students' geometry achievement?" was examined using their associated hypothesis which was in the null form and it was tested at a significance level of 0.05.

The following hypothesis is stated for the main research question:

Null hypothesis (H_0): There is no significant difference in 4th-grade students' geometry achievement in two groups after instruction using and without using concrete materials.

Alternative Hypothesis (H_1): The instruction using concrete materials is more significant.

To test the hypothesis, a test of siginificant difference between two means in a small sample (t-test) was used and tested at the significance level of 0.05 (Rebecca Bevans, 2022 rev.)

Here degree of freedom = 13+13-2 = 24

The t-value is 1.711 for a 5 % level of significance.

From table 4,

Pooled variance = $\frac{1}{n_1 + n_2 - 2}\left\{\Sigma X_1^2 - \frac{(\Sigma X_1)^2}{n_1} + \Sigma X_2^2 - \frac{(\Sigma X_2)^2}{n_2}\right\}$

= 46.3

t value = $\frac{\overline{X_1} - \overline{X_2}}{S_p\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}$ = 1.99

Since the calculated t-value is greater than its critical value, the null hypothesis is rejected. Thus, it proves that the instruction using concrete materials is more effective.

Again, the same test (t-test) was administered on the achievements of students in the Experimental Group gender-wise. Their achievements are listed below:

Table 5: Gender-wise Post-test Marks Distribution in the Experimental Group

Girls	Boys
17	12
33	15
20	25
10	24
23	42
29	30
36	

Table 6: Analysis II

Test of significant difference between the average achievement of two groups concerned with gender in the Experimental Group

Gender	Number of Participants	Mean Achievement	Pooled Variance	Critical t-value	Calculated T-value
Girls	7	24	99.58	2.201	0.021
Boys	6	24.67			

For a 5% level of significance, the t-value for the degree of freedom 11 is 2.201 assuming it is a two-tailed test and its calculated value is 0.021. Hence, the null hypothesis is accepted and it concludes that there is no remarkable difference in the achievement concerning gender division. Gender difference doesn't affect achievement.

Similarly, testing the comparison of achievements between the Janajati group and others, the researcher got the following the results.

Table 7: Analysis III

Test of significant difference between the average achievements of two groups concerned with the caste in the experimental group

Caste	Number of Participants	Mean Achievement	Pooled Variance	Critical T-value	Calculated T-value
Janajatis	9	22.22	88.142	1.796	0.213
Others	4	29			

Here, the significant deviation between the achievement concerning caste was tested. The purpose was to examine the effect of the experiment concerning ethnicity. It was claimed that the achievement score of other castes except for Janajati (majority of Darai and Tharu) was higher. However, the test proved that there was no significant difference between the achievements of the two groups.

The second research question in the study was related to fourth-grade students' attitude and feelings about instruction with concrete materials. For this purpose the researcher conducted an interview which included open-ended questions. Students' answers were categorized as "enjoyment", "anxiety", and "easiness". According to the responses of the Experimental Group to the interview questions, the researcher came to draw the following results and discussion.

The majority of participants in the Experimental Group felt that the learning based on manipulation of the materials in geometry was more pleasant and effective than learning without the use of manipulatives. They were found excited at the prospect of seeing the materials. Ram Chaudhary (name changed) said, "I both enjoyed and learned together with these materials". From his expression, it is clear that his learning through manipulative objects was practicable and achievable. Rita Darai (name changed) also stated, "I am very happy in present mathematics classes." Her expression also indicates that the mathematics class using manipulative materials is more effective and interesting. Concerning Gopal Dhungana's (name changed) interview, he previously used to feel bored in mathematics class. But he was found more curious and diligent after the teacher started using manipulative materials in geometry class.

In response to the questions related to mathematical anxiety, another student from Chaudhary community answered, "Earlier, I used to be anxious when I came across the questions. But now I don't feel so." His answer infers that mathematics anxiety decreases while concrete materials are used in teaching mathematics. Rima Tamang's (name changed) response was, "I don't feel hesitation when I see a new problem in my book". This expression also indicates that there is no anxiety and hesitation while facing new problems in mathematics. Students feel ease with the problem and find out the correct solution on their own. It shows that manipulation of objects in geometry learning is effective to reduce mathematics anxiety in students.

The study revealed that concrete materials not only helped in reducing anxiety and made the mathematics class enjoyable but also provided an easy way of solving mathematical problems. Along the same line, the researcher wanted to find out the feeling of ease or difficulty while solving a mathematical problem. When asked, "How do you feel about the solution to the problems in geometry?" Hari Darai (name changed) said, 'The lessons in which concrete materials are used are easier to understand than the other lessons. "It implies that the objectives of the lesson are achieved, and the learner gets a clear concept of the contents in the lesson. The next student, Mina Chaudhary (name changed) said, "When I come across a new problem related to my lesson, I can solve the problem easily after attending such classes." These responses clarify that the students are much more familiar with the problem and they can easily find out the solution to the problem if they are instructed through manipulatives. The teacher is also contented to use the new method as it significantly increases the learning outcomes.

Conclusion and Suggestions

The study concludes that instruction with manipulative objects is effective in geometry class as it increases the young learners' geometry achievement level and positive orientation. Students enjoy the classes based on learning with the manipulation of concrete objects. Moreover, students' excitement and curiosity about the manipulation of objects are powerful motivating factors to improve learners' comprehension and application of basic geometrical concepts. It further implicates that students feel happier in the classroom where concrete materials are used in the enjoyment category. In the anxiety category, the students become less anxious after the manipulation of concrete materials in instruction. In the easiness category, most of the students instructed with concrete objects feel at ease solving questions.

Close analysis and interpretation of the learners' achievements and positive perceptions of manipulative-based instructions suggest the stakeholders for bringing a paradigm shift in the way young learners are taught geometrical concepts. The innovation and enhancement in classroom pedagogy through the optimum and skilled use of concrete manipulative not only motivates the learners towards subject matter by avoiding math anxiety but also improves geometrical learning achievement. This opens up the avenues for making the students feel that mathematics learning is fun through student-centered teaching-learning activities. The school administration can encourage and train the teachers to implement the student-centered teaching approach, collect or construct appropriate teaching materials used in a real-life situation and use them in regular classes to improve the learning achievements as well as motivate the learners.

Limitations of the study and recommendations for further research

This study was limited to the effectiveness of instruction with manipulative materials on fourth graders' geometry learning achievement in the context of a public school in Khairahani Municipality, Chitwan. The researcher selected the samples of only 13 students for the Experimental Group and the Control Group each, and employed Posttest Only Control Group Design. Thus, additional research can be conducted in both private and public schools of other rural or urban areas with greater sample size, employing other experimental designs or quasi-experimental designs. Besides the post-test, the researcher conducted interviews only with 8 students in the present research. Future researchers can increase its size and explore the perception of the learners from both groups.

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