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Enhancing mathematical communication and learning independence through learning cycle 6E model with dynamic geometry software: A study of vocational high school students

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Original Article

Enhancing mathematical communication and learning independence through learning cycle 6E model with dynamic geometry software: A study of vocational high school students

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Abstract
Mathematical communication ability and learning independence are essential 21st-century competencies that remain underdeveloped in vocational mathematics education, where students often perceive mathematics as irrelevant to their careers. This quasi-experimental study investigated the effectiveness of integrating the Learning Cycle 6E model with Dynamic Geometry Software (GeoGebra) in improving these competencies among vocational high school students. Sixty-nine tenth-grade students from the Marketing Skills Program were assigned to experimental (n=35) and control (n=34) groups through random sampling. The experimental group received instruction using the six-phase Learning Cycle 6E model (engage, explore, explain, elaborate, evaluate, extend) integrated with GeoGebra, while the control group received conventional expository instruction. Data were collected through mathematical communication tests and learning independence questionnaires administered as pretest and posttest. Normalized gain (N-Gain) analysis was employed to measure improvement effectiveness. Results demonstrated that the experimental group achieved significantly higher improvement in mathematical communication ability (N-Gain = 0.62) compared to the control group (N-Gain = 0.44), representing a 40.9% advantage. Similarly, learning independence improved significantly more in the experimental group (N-Gain = 0.51) versus the control group (N-Gain = 0.26), nearly doubling the control group's gain. Statistical analyses confirmed both differences were significant ($p < 0.05$) with large effect sizes. These findings provide empirical evidence that integrating constructivist pedagogy with dynamic technology effectively enhances both cognitive and metacognitive competencies in vocational mathematics education, offering a practical framework for revitalizing mathematics instruction to meet contemporary educational demands and career-relevant applications.

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1. Introduction

Mathematics education plays a critical role in developing students' cognitive abilities, particularly in fostering logical reasoning, analytical thinking, and problem-solving skills. However, two essential competencies that remain challenging to develop in mathematics classrooms are mathematical communication ability and learning independence. Mathematical communication ability enables students to express, discuss, and justify mathematical ideas coherently, while learning independence empowers students to self-regulate their learning processes. Although these competencies are important, research consistently shows that they are underdeveloped in traditional classrooms, where teacher-centered teaching dominates and students remain passive recipients of knowledge. This concern is particularly acute in vocational education settings, where students often perceive mathematics as irrelevant to their career aspirations, leading to lower motivation and engagement. According to Piaget's theory, children's cognitive development occurs independently through interaction with their physical environment, with structured and universal stages (Ramesh, 2022). This constructivist perspective underscores the importance of active learning experiences that position students as knowledge constructors rather than passive information receivers.

The National Council of Teachers of Mathematics (NCTM) emphasizes mathematical communication as a fundamental process standard, highlighting its role in helping students organize, consolidate, and clarify their mathematical thinking. Similarly, Zimmerman's theory of self-regulated learning underscores the importance of learning independence in enabling students to actively plan, monitor, and evaluate their own learning. However, conventional teaching methods—characterized by lecture-based instruction, limited student interaction, and minimal opportunities for exploration—fail to adequately address these competencies. This pedagogical gap necessitates the adoption of more innovative, student-centered instructional approaches that align with constructivist principles and contemporary learning theories.

Various instructional models have been proposed to enhance mathematical communication and learning independence. Constructivist approaches, such as problem-based learning, inquiry-based learning, and learning cycle models, have demonstrated potential in activating student engagement and promoting conceptual understanding. Among these, the Learning Cycle model has gained recognition for its systematic approach to knowledge construction through phases of exploration, explanation, and application. Research by Lawson et al. and Bybee has shown that learning cycle models effectively support conceptual change and deeper understanding in science and mathematics education. The Learning Cycle 6E model, an enhanced version developed by Eisenkraft, extends the traditional 5E model by adding an "extend" phase, providing additional opportunities for students to transfer knowledge to new contexts and strengthen their learning independence. The Learning Cycle model is a constructivism-based learning model where students actively build their own knowledge through a series of systematic learning phases. The Learning Cycle 6E model is a development of the Learning Cycle 5E model developed by Eisenkraft (Diyyab & Aly, 2021). This model consists of six learning phases: engage, where teachers arouse students' interest and curiosity through questions, demonstrations, or contextual problems to activate prior knowledge; explore, where students investigate concepts through group observations, experiments, or manipulation of mathematical objects; explain, where students articulate their findings to peers and teachers, with mathematical communication becoming critically important; elaborate, where students apply concepts to new situations or more complex problems; evaluate, where both teachers and students assess understanding through tests, presentations, or projects; and extend, where students connect learned concepts to other contexts or real-life situations. The six phases of the Learning Cycle 6E model create multiple opportunities for students to articulate their mathematical thinking, justify their conclusions, and receive feedback from peers and teachers, while simultaneously providing structured support for developing learning independence as students gradually assume greater responsibility for their own learning processes.

Furthermore, the integration of technology in mathematics education has opened new possibilities for enhancing learning experiences. Dynamic Geometry Software is software that allows users to create, manipulate, and explore geometric objects dynamically and interactively (Öndeş, 2021). Dynamic Geometry Software such as GeoGebra, Cabri Geometry, and Geometer's Sketchpad, allows students to manipulate geometric objects dynamically, visualize abstract concepts, and discover mathematical relationships through interactive exploration. Studies by Hohenwarter and Preiner, as well as Laborde, have demonstrated that Dynamic Geometry Software facilitates conceptual understanding, supports multiple representations, and enhances students' engagement in mathematical investigation. The dynamic and visual nature of Dynamic Geometry Software creates an environment conducive to mathematical discourse, as students can demonstrate their reasoning visually and collaboratively explore mathematical ideas. The interactive nature of Dynamic Geometry Software encourages students to take initiative in their learning, formulate conjectures independently, and develop self-regulatory skills. When integrated thoughtfully into instruction, such technology serves as a powerful cognitive tool that supports both the communication of mathematical ideas and the development of autonomous learning behaviors.

Despite these promising developments, previous research reveals several critical limitations. First, while studies have examined the Learning Cycle 6E model and Dynamic Geometry Software separately, limited research has investigated the synergistic effects of combining these two approaches. Most existing studies focus on either the pedagogical model or the technological tool in isolation, without exploring how their integration might amplify learning outcomes. Second, research on the Learning Cycle 6E model has predominantly focused on conceptual understanding and academic achievement, with insufficient attention to process skills such as mathematical communication. Third, the development of learning independence through technology-enhanced constructivist approaches remains underexplored, particularly in secondary mathematics education. Fourth, much of the existing research has been conducted in Western educational contexts, with limited evidence from diverse cultural and educational settings, such as vocational schools in Indonesia, where students face unique challenges in mathematics learning. These gaps indicate a need for empirical investigation into how the Learning Cycle 6E model, when integrated with Dynamic Geometry Software, can simultaneously develop both mathematical communication ability and learning independence.

The combination of these two approaches offers compelling theoretical advantages. The Learning Cycle 6E model provides a structured pedagogical framework that guides students through systematic exploration and knowledge construction, while Dynamic Geometry Software serves as a powerful cognitive tool that supports visualization, experimentation, and mathematical reasoning. In this integrated approach, mathematical communication skills are expected to improve through the explore, explain, and elaborate stages, where students discuss, state, analyze, and evaluate mathematical ideas, using mathematical symbols and structures to model situations or problems with GeoGebra in their groups so that solutions can be obtained and presented to other groups. Meanwhile, student learning independence is expected to increase through the evaluate and extend stages, where students are able to draw conclusions in learning and solve more complex problems or projects independently using Dynamic Geometry Software (GeoGebra).

The use of GeoGebra is purposefully integrated at each stage of the Learning Cycle 6E model. In the engage stage, GeoGebra provides stimulus questions to motivate students' interest and curiosity in the material about linear functions and quadratic functions. During the explore stage, GeoGebra facilitates discussions where students draw graphs of various linear and quadratic functions with coefficient changes, identify intersection points with the x and y axes, analyze peak positions and axes of symmetry on quadratic function graphs, and explore graphs of contextual problems. In the explain stage, GeoGebra is used to present theoretical concepts regarding linear functions, including equation writing and graphic characteristics, visualize graphic changes, and respond to and explain solutions to contextual problems. The elaborate stage employs GeoGebra to guide students in verifying calculation results and drawing function graphs according to given criteria, enabling them to draw conclusions. During the evaluate stage, GeoGebra assesses students' understanding through questions about determining equations of linear and quadratic functions from graphic images of their functions. Finally, in the extend stage, GeoGebra provides challenges for students to connect concepts with linear function problems, encouraging them to carry out research or independent projects on contextual problems about linear and quadratic functions according to their expertise concentration. This systematic integration ensures that technology use is purposeful and pedagogically grounded, supporting both the development of mathematical communication through shared visual references and the cultivation of learning independence through opportunities for self-directed exploration and immediate feedback.

The scientific novelty of this study lies in three key aspects. First, it examines the combined effect of the Learning Cycle 6E model and Dynamic Geometry Software on two critical but distinct learning outcomes—mathematical communication ability and learning independence—simultaneously. This dual focus addresses the multidimensional nature of mathematics learning and responds to contemporary educational demands for both cognitive and affective skill development. Second, this study contributes empirical evidence from a vocational education context, specifically the Marketing Skills Program, where mathematics instruction often faces unique challenges due to students' diverse academic backgrounds and career orientations. In vocational settings, students frequently view mathematics as disconnected from their future careers, leading to disengagement. By demonstrating how innovative pedagogy and technology can enhance both communication and independence in this challenging context, this study provides valuable insights for vocational mathematics education reform. Third, the study employs rigorous quasi-experimental methodology with multiple assessment instruments to capture both the quantitative changes in learning outcomes and the quality of improvement through normalized gain analysis. This methodological rigor strengthens the validity and reliability of findings, providing robust evidence for educational practice and policy.

Therefore, the purpose of this study is to examine whether there are significant differences in the improvement of mathematical communication ability and learning independence between students who receive the Learning Cycle 6E model assisted by Dynamic Geometry Software and students who receive conventional learning. Specifically, this research aims to: (1) investigate the difference in the improvement of mathematical communication ability between students in the experimental group and the control group, and (2) investigate the difference in the improvement of learning independence between students in the experimental group and the control group. By addressing these objectives, this study seeks to provide empirical evidence for the effectiveness of integrating constructivist pedagogy with dynamic technology in enhancing essential 21st-century mathematical competencies. The findings are expected to inform instructional practices in vocational mathematics education and contribute to the broader discourse on effective technology integration in constructivist learning environments.

2. Method

The design used in this study is a quantitative approach with a quasi-experimental method using Nonequivalent Control Group Design, which compares an experimental group with a control group where both groups are not equivalent. Both groups are given a pretest and initial questionnaire scale, then subjected to treatment. The experimental group receives treatment in learning using the Learning Cycle 6E model assisted by Dynamic Geometry Software, while the control group continues to use the conventional learning model, namely expository. Conventional learning is a teacher-centered learning approach where the teacher becomes the main source of information and knowledge (Alam, 2023). In conventional learning, the learning process generally follows the pattern: the teacher explains the material, provides example problems, and students work on practice problems. The dominant methods used are lectures, one-way question and answer (from teacher to student), and assignments. Characteristics of conventional learning include: (1) teacher as the center of learning and main information provider; (2) students play a passive role as information recipients; (3) communication tends to be one-way from teacher to students; (4) emphasis on memorization and routine procedures; (5) few opportunities for exploration and discussion; (6) use of learning media limited to blackboards and textbooks. Subsequently, a posttest and final questionnaire scale are administered to measure the effect of the treatment on both groups. The sampling in this study uses a random sampling technique, which is a sampling method where each member of the population has an equal opportunity to be selected as part of the sample (Suriani, 2023).

2.1 Design

According to Assuah et al. (2022), the non-equivalent Control Group Design scheme can be described like this following Table 1.

Table 1
Scheme of non-equivalent Control Group Design Group Pre-test Treatment Post-test

Group	Pre-test	Treatment	Post-test
Experiment	T1	X	T2
Control	T1	0	T2

Source: Sugiyono (2013) in Assuah

Table 1 shows that population is a collection area of all (totality) subjects or the value of the results of an observation that has certain characteristics. The population in this study were grade X students at at a vocational school in Sukoharjo, Central Java, in the 2024/2025 academic year which was divided into 11 study groups with a total of 310 students. Sampling in this study used a random sampling technique, which is a sampling method in which each member of the population has the same opportunity to be

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selected as part of the sample (Makwana et al., 2023). The main purpose of this technique is to obtain a representative sample, which can represent the entire population fairly without bias. The random sampling technique used is cluster random sampling. Group random sampling divides the population into groups, then randomly selects several groups to become experimental groups and control groups (Firmansyah & Dede, 2022).

2.2 Participants

This study involved 69 tenth-grade students from a vocational high school in Sukoharjo, Central Java, selected from a population of 310 students distributed across 11 classes during the 2024/2025 academic year. Cluster random sampling technique was employed to select participants while maintaining the integrity of existing classroom structures. The main purpose of this technique was to obtain a representative sample that could fairly represent the entire population without selection bias. From three available classes in the Marketing Skills Program, class X PM.3 (n=35) was randomly assigned to the experimental group and class X PM.2 (n=34) to the control group. This random assignment procedure ensured baseline equivalence between groups, minimizing potential confounding variables and enhancing the internal validity of the research design.

The selection of Marketing Skills Program students as participants addresses an important gap in mathematics education research. Students in vocational programs, particularly those in business-oriented tracks like marketing, often perceive mathematics as disconnected from their career trajectories, leading to diminished motivation and engagement (Fata et al., 2022). This perception, however, contradicts the practical demands of marketing careers, where mathematical communication skills are indispensable. Marketing professionals must analyze sales data, forecast demand patterns, calculate profit margins, evaluate pricing strategies, and communicate quantitative findings effectively to clients and stakeholders. By demonstrating the effectiveness of an innovative pedagogical approach in enhancing mathematical communication and learning independence within this challenging vocational context, this study contributes practical insights for making mathematics education more relevant, engaging, and aligned with students' career goals.

2.3 Data Collection

The research steps carried out were the preparation of a learning implementation plan using the Learning Cycle 6E model and Dynamic Geometry Software, limited testing of mathematical communication skills and independent learning, carrying out pretests and the initial scale of the questionnaire, implementing learning, carrying out posttests and the final scale of the questionnaire, and testing hypotheses. The data collection techniques used in the research were test and questionnaire. While the test is a series of questions, worksheets, or the like that are used to measure the knowledge, skills, talents, and abilities of the research subject (Illene et al., 2023). The test in this study was administered to determine the improvement in students' mathematical communication skills before and after participating in learning using Learning Cycle 6E model and Dynamic Geometry Software.

The National Council of Teachers of Mathematics (NCTM) establishes mathematical communication as one of the process standards in mathematics learning. Mathematical communication includes students' ability to represent mathematical concepts using symbols, graphs, tables, diagrams, or other forms of representation, as well as explain problem-solving processes in writing. Indicators of mathematical communication ability include: (K1) ability to express mathematical ideas through speech, writing, demonstration, and visual representation; (K2) ability to understand, interpret, and evaluate mathematical ideas both orally and in other visual forms; (K3) ability to use mathematical terms, notations, and structures to present ideas, describe relationships, and model situations. Developing students' mathematical communication abilities is very important because through communication, students can explore and consolidate their mathematical thinking, and clarify their understanding of mathematical concepts (Maulyda, 2020). When students are asked to communicate their mathematical ideas, they will try to organize and clarify their thoughts, so that conceptual understanding becomes deeper. The items in the test instrument were arranged according to the grid as shown in Table 2.

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Table 2
Test Instrument Grids

Number	Basic Competence	Subject Matter	Problem Indicator	Problem Number	Mathematical Communication Ability Indicator
1.	Explain and find functions (especially linear functions, quadratic functions, and rational functions) formally including notation, origin, and symbolic expressions, as well as sketch their graphs.	Linear Functions and Quadratic Functions	Identify linear functions and quadratic functions	1, 2 3	K1, K2 K2
			Draw graphs of linear functions and quadratic functions	1, 2	K1, K2
2.	Analyse the characteristics of each graph (intersection points with axes, cusp, asymptotes) and changes in the graph of a function due to transformations of the graph.		Analyse the effect of coefficients on the graphs of linear functions and quadratic functions	1, 2	K1, K2
			Solve contextual problems related to linear functions and quadratic functions	4 5	K3, K2 K3, K2

Source: Primary Data

Table 2 shows that, this test was given at the beginning before the learning began (pre-test) and at the end (post-test) after the learning process of 4 meetings. The test instrument used is in the form of a description question (essay) with the material of linear functions and quadratic functions as many as 5 items that can show the ability of students to meet the indicators of mathematical communication skills to be studied.

Mathematical communication ability and learning independence are two important aspects that need to be developed in mathematics learning. Conventional learning that is teacher-centered and tends to be passive is less effective in developing both aspects (Emanet & Kezer, 2021). Meanwhile, the questionnaire instrument uses a Likert scale which has gradations from very positive to very negative, namely (1) Always, (2) Often, (3) Sometimes, (4) Rarely, and (5) Never. This instrument includes 7 indicators of independent learning with 26 statements. Learning independence or self-regulated learning is students' ability to organize and control their own learning processes. Zimmerman in Hariyadi (2023), defines learning independence as a process in which students actively plan, monitor, and evaluate their own learning. Students with high learning independence are able to set learning goals, choose appropriate learning strategies, monitor their learning progress, and reflect on their learning outcomes. The way to presented table like this following Table 3.

Table 3
Questionnaire Grid

Number	Independent learning Indicator	Question Number	Number of Questions
1	Ability to set learning goals	1, 2, 3	3
2	Ability to manage time and study management	4, 5, 6, 7	4
3	Ability to choose and apply learning strategies	8, 9, 10, 11	4
4	Ability to reflect on the process and evaluate learning outcomes	12, 13, 14, 15	4
5	Having motivation and responsibility for learning	15, 17, 18, 19	4

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6	Having initiative and creativity in learning	20, 21, 22, 23	4
7	Ability to communicate and collaborate	24, 25, 26	3

Source: Primary Data

Table 3 shows that, the questionnaire was given to obtain information on the increase in student independent learning before and after using Learning Cycle 6E model and Dynamic Geometry Software. This questionnaire is a closed questionnaire given in the form of a google form, where students can express their opinions and their hearts according to the conditions. The questionnaire will be given at the beginning before the learning begins (initial scale) and at the end (final scale) after the learning process of 4 meetings.

2.4 Data Analysis

Before the test instruments and questionnaires were used to collect data on the main sample, a limited testing stage was carried out. The aim of this stage is to ensure that the instrument used meets the requirements as a good measuring tool, namely valid (measuring what it should measure) and reliable (consistent and reliable). Instrument validity is the precision, accuracy and accuracy of the measuring instrument regarding what it should measure (Bahariniya, 2021). This validity test consists of (1) content validity is the accuracy of the instrument in terms of the material being evaluated, which is a representative sample of the knowledge that students must master, (2) criterion/face validity is the accuracy of sentence structure, clarity of diagrams, symbols, etc., (3) construct validity is the completeness of the aspects that must be contained in the instrument. Validity testing in this research used the judgment of three validators from colleague, who examined the suitability of the test instrument items with the planned grid and questionnaire (validity test instrument attached). Meanwhile, normality testing was carried out with the help of SPSS version 27 using Pearson Correlation by comparing the calculated r value of the total value with the r table. If r count > r table, then the instrument item/item is valid and if r count < r table, then the instrument item/item is invalid. The r table value uses a significance level of $\alpha = 0.05$ (2-way) or $\alpha = 0.01$ (1-way).

Instrument reliability is the trustworthiness, reliability, consistency, stability and consistency of an instrument (Pandian et al., 2023). Thus, reliability shows the extent to which a measuring instrument can be trusted or relied upon. In this reliability test, established correlation rules can be used to determine whether an instrument has high, medium or low reliability. The correlation value obtained shows the level of reliability of the instrument. Test the reliability of valid instrument items, using Cronbach's Alpha as a coefficient to find out how consistently the questions in the instrument measure the same variable. If the Cronbach's Alpha value is greater than 0.6, then the instrument is considered reliable or consistent. This value of 0.6 is used as the minimum limit in reliability tests, because it is a value that is considered good enough to measure the internal consistency of an instrument. Reliability testing was carried out with the help of SPSS version 27.

This research method goes through two main stages: limited testing of test instruments and questionnaires to ensure validity and reliability, and quantitative data analysis consisting of descriptive analysis is used to provide a general overview of the data characteristics of each research variable. The descriptive statistics presented include mean (average), standard deviation, minimum value, maximum value, as well as data presentation in the form of frequency distribution tables and diagrams/graphs and inferential analysis used (1) N-Gain (Normalized Gain) to determine the magnitude of improvement in students' understanding of a material by comparing the improvement in scores between pretest and posttest (Fahlevi & Yuliani, 2021), (2) The Independent Sample T-Test is a parametric statistical test used to compare the means of two unrelated groups (Putri et al., 2023). This test requires prerequisite tests including normality test and homogeneity test. (3) Welch's T-Tes, if the data is normally distributed but not homogeneous. This is a modified version of the independent sample t-test that is used when the variances between two groups are not equal (Nissa, 2024), and (4) Mann-Whitney Test, if the data obtained is not normally distributed and both variances are not homogeneous, the Mann-Whitney test is used (Mallini et al., 2023). This is a non-parametric statistic for testing comparative hypotheses of two independent samples.

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3. Results and Discussion

3.1 Results

The Learning Cycle 6E model and Dynamic Geometry Software for the experimental group and the conventional learning model for the control group, each for four meetings. The distribution of material at each meeting can be seen as following in Table 4.

Table 4

Material Distribution

Activities	Material
1	Describe and identify linear functions, and analyze changes in linear function graphs
2	Describe and identify quadratic functions, and analyze changes in the graph of quadratic functions
3	Solving contextual problems of linear functions
4	Solve contextual problems of quadratic functions

Source: Primary Data

Table 4 shows that, the learning process for the material on linear functions and quadratic functions was carried out in 4 meetings, with Learning Cycle 6E model and Dynamic Geometry Software (GeoGebra) given to the experimental group, while conventional model learning was given to the control group.

In each learning activity of Learning Cycle 6E model and Geogebra the teacher conveys the aims and objectives of learning with material on linear functions and quadratic functions using the free GeoGebra application on each student's handphone, although occasionally students will be invited to study in the computer laboratory. The teacher explains the indicators that students must understand according to the distribution of material for each meeting. The teacher invites students to apperceive the material at the previous meeting.

Starting the core activities at the engage stage, the teacher conditions the learning activities by providing stimulus questions to motivate students' interest and raise students' curiosity about the material to be studied through pictures of contextual examples of linear functions that can be depicted using the GeoGebra application. Then, through questions and answers, the teacher tries to increase students' understanding of basic knowledge regarding the benefits of the material to be studied. Students give examples of the application of linear functions in everyday life orally.

Continuing the learning process, after the engage stage where students really pay attention and are fully involved in learning, the teacher groups students in the explore stage. Students in their groups try to describe various possible forms of linear functions or quadratic functions, as in the following Figure 1.

Figure 1

Explore Stage

Figure 1 shows that students are able to draw and identify linear function graphs, as well as analyze changes in their graphs using GeoGebra effectively. Students and their groups will strive to learn

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independently by changing various input coefficient values followed by changes in the graph. After students explore various forms of graphs of linear functions, the teacher gives problems on students' worksheets which are solved in discussion.

At the explain stage, the teacher facilitates students to present the results of the discussion, express opinions in groups in providing solutions to the problems presented. This stage also provides opportunities for other groups to provide responses, communicate with each other by defending each other's opinions or receiving input from other groups. Activities at this stage are shown in the following Figure 2.

Figure 2
Explain stage

Figure 2 shows that students are able to communicate their mathematical ideas in analyzing linear function graphs using GeoGebra correctly.

This is followed by the elaborate stage, where the teacher provides reinforcement of problem-solving solutions that have been discussed, presented and communicated between groups, so that a conclusion is reached. The teacher tries to motivate students to develop the concept of understanding in solving problems independently. In evaluating knowledge and learning experience at the evaluation stage, the teacher assesses the learning process with observation sheets and assesses student learning outcomes by providing problems that can be solved independently. In this problem, students are asked to describe and identify linear functions, as well as analyze changes in their graphs. Based on the results of identification and analysis of students' answers depicting linear function graphs using GeoGebra, it can be seen that most students were able to answer correctly.

Students use the GeoGebra application to draw graphs, analyze changes in the graph, and draw conclusions. Furthermore, at the end of the meeting, in the extend stage the teacher tries to expand students' knowledge of linear function material, by providing challenges for students to be able to connect concepts to different, more complex problems.

The results of each stage of Learning Cycle 6E model and Geogebra integration which help improve mathematical communication skills and learning independence are shown in Figure 3.

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Figure 3

The results of Learning Cycle 6E model and Geogebra

Engage Stage	Explore Stage	Explain Stage	Elaborate Stage	Evaluate Stage	Extend Stage
Students pay full attention to the teacher presenting examples of graphing functions using GeoGebra, which fosters curiosity to learn more about the material.	Students are able to draw and identify function graphs and independently analyze changes in graphs using GeoGebra. Students are also able to mathematically communicate various changes in coefficient values, which are then followed by changes in the graph.	Students are able to correctly communicate their mathematical ideas in analyzing linear function graphs using GeoGebra and present them independently.	Students independently use GeoGebra to strengthen their understanding of various problem contexts and function graphs.	Students are motivated to be more independent and active in learning using GeoGebra as an interactive learning medium that encourages creativity.	Students expan their knowledg as a challenge i independently communicating mathematically about a contextual problem using GeoGebra.

Source: Primary Data

After the learning was carried out, a post-test and questionnaire were then given as the final scale to the experimental group and control group.

Meanwhile, the conventional learning referred to in this research is the expository model. Where the teacher's activity in this learning model is to explain the material orally, provide definitions, principles and draft (Heryadi & Sundari, 2020). While students just listen and take notes. The steps for implementing the expository model used in this research are that the teacher prepares lesson material systematically explaining the lesson material clearly and completely, connecting the lesson material with the knowledge that students already have, helping students draw conclusions from the material that has been presented, and providing opportunities for students to apply the material they have learned in certain activities or assignments.

3.1.1 N-Gain

N-Gain to determine the difference in mathematical communication ability and learning independence between students who received the Learning Cycle 6E model assisted by Dynamic Geometry Software. The N-Gain test uses the following formula:

$$N - Gain = \frac{Skor\ Posttest - Skor\ Pretest}{Skor\ Ideal - Skor\ Pretest} \quad (1)$$

From the pretest and posttest results of mathematical communication ability, the N-Gain was obtained and presented in a bar chart in Figure 4.

Figure 4

Bar Chart of N-Gain for Mathematical Communication Ability

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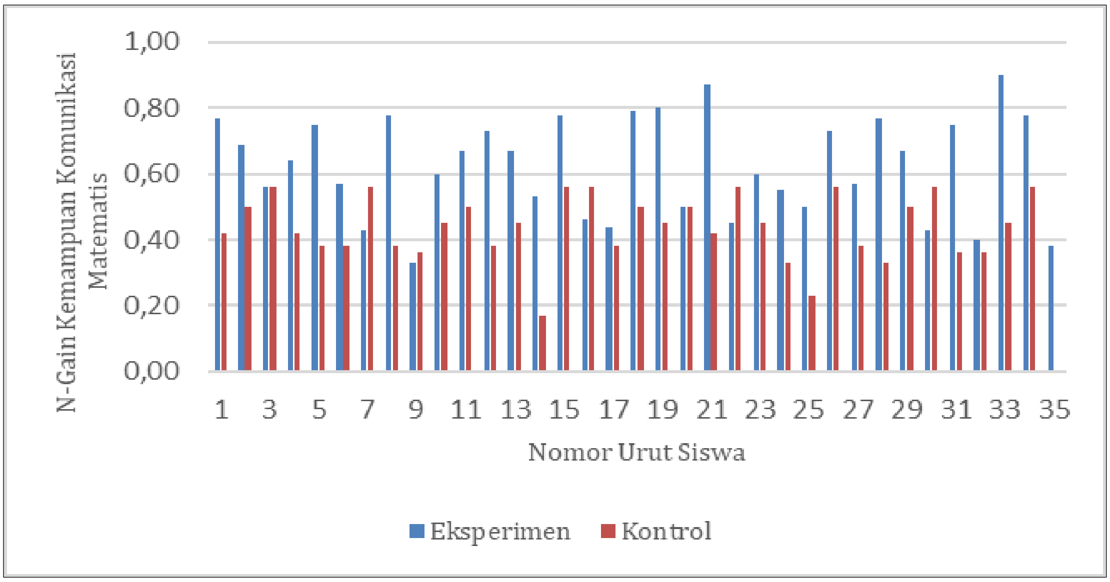

From Figure 4, the maximum value, minimum value, mean, and standard deviation of the N-Gain for mathematical communication ability are presented in Table 5.

Table 5
Maximum, Minimum, Mean, and Standard Deviation Values of N-Gain for Mathematical Communication Ability

Value	*N-Gain*	
	Experiment	Control
Maximum	0.90	0.56
Minimum	0.33	0.17
Average	0.62	0.44
Standard deviation	0.15	0.10

From Table 5, it is known that the mean N-Gain of the Experimental group (0.62) is significantly higher than the Control group (0.44). This proves that the Learning Cycle 6E model assisted by Dynamic Geometry Software can help improve mathematical communication ability.

Meanwhile, from the results of the initial scale and final scale of the learning independence questionnaire, the N-Gain was obtained and presented in a bar chart in Figure 5.

Figure 5
Bar Chart of N-Gain for Student Learning Independence

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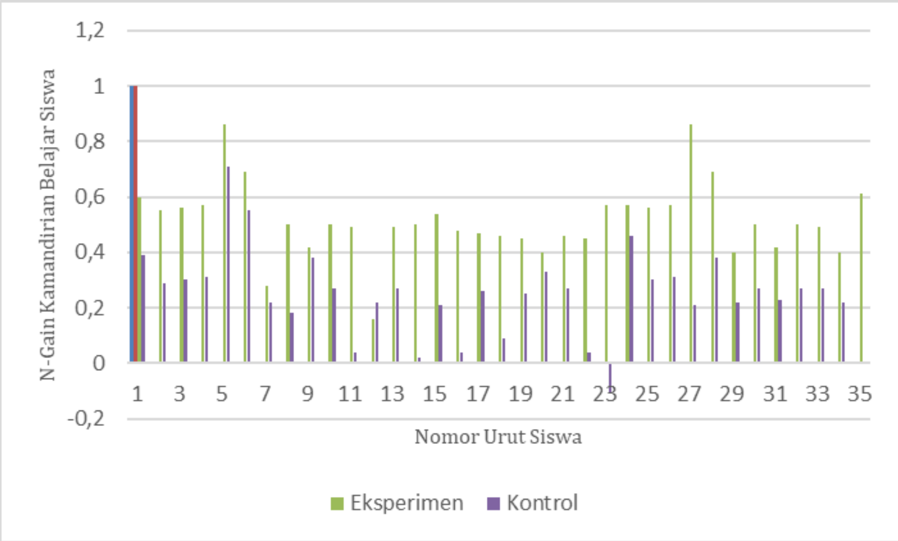

From Figure 5, the maximum value, minimum value, mean, and standard deviation of the N-Gain for student learning independence are presented in Table 6.

Table 6
Maximum, Minimum, Mean, and Standard Deviation Values of N-Gain for Student Learning Independence

Value	*N-Gain*	
	Experiment	Control
Maximum	0.86	0.71
Minimum	0.16	-0.11
Average	0.51	0.26
Standard deviation	0.13	0.15

Source: Primary Data

From Table 6, it is known that the mean N-Gain of the Experimental group (0.51) is higher than the Control group (0.26). This proves that the Learning Cycle 6E model assisted by Dynamic Geometry Software can help improve student learning independence.

3.1.2 Normality Test

The data normality test was conducted to test the normality assumption of the data as a prerequisite for using the independent sample t-test. The normality test was performed using SPSS version 27 with the Kolmogorov-Smirnov test at a significance level of $\alpha = 0.05$. The tested data is said to be normally distributed if the Sig. value in the column corresponding to the Kolmogorov-Smirnov test > α, and if otherwise, the tested data is not normally distributed. The results of the normality test for the improvement data of mathematical communication ability of students who received the Learning Cycle 6E model assisted by Dynamic Geometry Software and conventional learning are presented in Table 7.

Table 7
Normality Test for Mathematical Communication Ability Improvement

		Kolmogorov-Smirnov		
		Statistic	df	Sig.
N-Gain	Experiment	.127	35	.163
	Control	.128	34	.175

Source: Primary Data

From Table 7, the Sig. values for both the Experimental group and Control group > $\alpha = 0.05$, which means the data is normally distributed, so it is continued with the homogeneity test.

Meanwhile, the results of the normality test for the improvement data of student learning independence who received the Learning Cycle 6E model assisted by Dynamic Geometry Software and conventional learning are presented in Table 8.

Table 8
Normality Test for Student Learning Independence Improvement

		Kolmogorov-Smirnov		
		Statistic	Df	Sig.
N-Gain	Experiment	.167	35	.015
	Control	.179	34	.008

Source: Primary Data

From Table 8, the Sig. values in the column corresponding to the Kolmogorov-Smirnov test for both groups < α = 0.05, which means the data is not normally distributed, so it is continued using a non-parametric test (Mann-Whitney U).

3.1.3 Homogeneity Test

The data homogeneity test was conducted to determine whether the variance of the improvement data for mathematical communication ability and student learning independence from both groups is homogeneous or not homogeneous. The homogeneity test for variance of the improvement data for mathematical communication ability and student learning independence who received the Learning Cycle 6E model assisted by Dynamic Geometry Software and conventional learning was performed using SPSS version 27 with Levene's Test at a significance level of α = 0.05. Both tested data are said to have homogeneous variance if the Sig. value ≥ α, and if otherwise, both tested data have non-homogeneous variance. The results of the homogeneity test for the improvement data of mathematical communication ability of students who received the Learning Cycle 6E model assisted by Dynamic Geometry Software and conventional learning are presented in Table 9.

Table 9
Homogeneity Test for Mathematical Communication Ability Improvement

		Levene Statistic	df1	df2	Sig.
N-Gain	Based on Mean	11.208	1	67	.001
	Based on Median	10.535	1	67	.002
	Based on Median and with adjusted df	10.535	1	62.949	.002
	Based on trimmed mean	11.223	1	67	.001

From Table 9, the Sig. Based on Mean < α = 0.05, which means the Levene's Test results show that the data does not have homogeneous variance, so it is continued using Welch's t-test.

3.1.4 Hypothesis Testing

3.1.4.1 Results of the First Hypothesis Test

The normality and homogeneity test results for mathematical communication ability in the Experimental and Control groups showed that the data is normally distributed but not homogeneous, so Welch t-test was performed, which is a modified version of the independent sample t-test used when the variance between two groups is not equal. This test adjusts the degrees of freedom to account for unequal variances, thus providing more accurate results. The results obtained are shown in Table 10.

Table 10
Welch t-test for Mathematical Communication Ability Improvement

Independent Samples Test					
	Levene's Test for Equality of Variances	*t-test for Equality of Means*			
		Sig. (2-tailed)	*Mean Differ ence*	*Std. Error Differ*	*95% Confidence Interval of the Difference*

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		F	*Sig.*	*T*	*df*			*ence*	*Lower*	*Upper*
N-Gain	*Equal variances assumed*	11.208	.001	5.980	67	.000	.18547	.03101	.12357	.24738
	Equal variances not assumed			6.017	58.126	.000	.18547	.03082	.12377	.24717

Source: Primary Data

From Table 10, the Sig. (2-tailed) value on Equal variances not assumed < α = 0.05, which means there is a significant difference in the improvement of mathematical communication ability between students who received the Learning Cycle 6E model assisted by Dynamic Geometry Software and students who received conventional learning.

3.1.4.2 Results of the Second Hypothesis Test

The normality test results for learning independence in the Experimental and Control groups showed that the data is not normally distributed, so the hypothesis test used was the Mann-Whitney test, which is a non-parametric statistic for testing comparative hypotheses of two independent samples. The results obtained are shown in Table 11.

Table 11

Mann-Whitney Test for Student Learning Independence Improvement

	N-Gain
Mann-Whitney U	99.500
WiLearning Cycleoxon W	694.500
Z	-5.953
Asymp. Sig. (2-tailed)	.000

From Table 11, the Asymp. Sig. (2-tailed) value < α = 0.05, which means there is a significant difference in the improvement of learning independence between students who received the Learning Cycle 6E model assisted by Dynamic Geometry Software and students who received conventional learning.

3.2 Discussion

The research results have answered the problem formulation, proving that the hypotheses are fulfilled: there is a significant difference in the improvement of mathematical communication ability between students who received the Learning Cycle 6E model assisted by Dynamic Geometry Software and students who received conventional learning in the Marketing Skills Program, and there is a significant difference in the improvement of learning independence between students who received the Learning Cycle 6E model assisted by Dynamic Geometry Software and students who received conventional learning. In the Engage stage, GeoGebra is used to provide stimulus questions to motivate student interest and curiosity (Khasanah & Nugraheni, 2022). In the Explore stage, GeoGebra is used in discussions to draw graphs of linear and quadratic functions with various coefficient changes, identify parts of graphs, and explore graphs from contextual problems (Losada, 2021). In the Explain stage, GeoGebra is used to present graphs of linear and quadratic functions, visualize graph changes, and respond to and explain solutions to contextual problems (Hudu et al., 2023). In the Elaborate stage, GeoGebra is used to guide students in verifying caLearning Cycleulation results and drawing function graphs according to given criteria until they can formulate conclusions (Sholikha & Siswono, 2023). In the Evaluate stage, GeoGebra is used to evaluate student understanding through problems given independently (Maryani, 2021). In the Extend stage, GeoGebra is used to provide challenges for students to connect concepts with material, thus encouraging students to carry out independent projects on contextual problems about linear and quadratic functions (Sun, 2023). According to Sudirman et al. (2023), all stages in the Learning Cycle 6E model can facilitate students to set learning goals, time management and learning management abilities (Engage stage), ability to choose and apply learning strategies (Explore stage), ability to communicate and collaborate (Explain stage), have learning

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motivation and responsibility (Elaborate stage), ability to reflect on processes and evaluate learning outcomes (Evaluate stage), and have learning initiative and creativity (Extend stage). The increased learning independence is evident from student activeness in group discussions, courage to express opinions, and initiative in finding problem solutions.

3.2.1 Significant Difference in Mathematical Communication Ability Improvement

The N-Gain normality test showed that the data on mathematical communication ability improvement for the Marketing Skills Program is normally distributed but not homogeneous, so Welch t-test was performed, which is an independent sample t-test using Equal variances not assumed. The Sig. (2-tailed) value < α = 0.05, which means there is a significant difference in the improvement of mathematical communication ability between students who received the Learning Cycle 6E model assisted by Dynamic Geometry Software and students who received conventional learning in the Marketing Skills Program. This difference was demonstrated during the learning process, where students were very enthusiastic about discussing and solving linear and quadratic function problems using the GeoGebra application. The Explain stage is crucial. After exploring with GeoGebra, student A might find pattern X, and student B might find pattern Y. The Explain stage forces them to externalize their internal findings. They have to negotiate, argue, and convince their classmates. Communication needs shift from “giving the final answer” to “narrating the process of discovery.”GeoGebra provides a visual and dynamic representation of abstract concepts. When students say, "Look, when I move slider a to the right, the curve gets 'slim,'" they are pointing to a concrete phenomenon that everyone can observe. This visualization acts as a cognitive anchor or shared "language". This reduces the cognitive load of imagining abstract concepts, so students can focus their mental resources on constructing arguments and describing relationships between variables.

These research results align with the research findings of Nurochmah et al. (2021), who concluded that the improvement in mathematical communication ability of students using the Learning Cycle 7E learning model is higher than students using conventional learning. Additionally, research by Lubis et al. (2023) concluded that there is a significant effect of using the Learning Cycle 5E model on students' mathematical communication ability. These research results are consistent with Widiastuti et al. (2023), who concluded that the 5E learning cycle is able to improve students' communication ability in learning mathematics. Furthermore, Nova et al. (2024) in their research concluded that lesson plans and student worksheets with the Learning Cycle 5E model that have been developed are effective in improving mathematical communication ability. The 7E learning cycle can be used to improve junior high school students' mathematical communication ability based on their thinking styles (Rahmy et al., 2020). Meanwhile, the application of GeoGebra learning media can improve students' mathematical communication ability in the subject of Two-Variable Linear Equation Systems (Arnanda et al., 2021). According to this research, through the use of GeoGebra, students can present their mathematical thinking visually and symbolically, which strengthens their mathematical communication ability. This is also consistent with research by Rahmatika et al. (2022), who concluded that the improvement in learning outcomes of students' mathematical communication ability taught with GeoGebra Software on trigonometry material is higher compared to learning outcomes without using GeoGebra Software.

3.2.2 Significant Difference in Learning Independence Improvement

The N-Gain normality test showed that the learning independence improvement data for both the Marketing Skills Program and Automotive Engineering Skills Program are not normally distributed, so the Mann-Whitney test was performed. The results showed that both Sig. (2-tailed) values < α = 0.05, which means there is a significant difference in the improvement of learning independence between students who received the Learning Cycle 6E model assisted by Dynamic Geometry Software and students who received conventional learning in both the Marketing Skills Program and Automotive Engineering Skills Program. This difference was demonstrated during the learning process, where students consciously and independently learned linear and quadratic function material using the GeoGebra application. Students even provided mutual assistance (peer tutoring) to clarify solutions to presented problems without waiting for teacher direction. The difference in student learning independence improvement fulfills seven indicators: ability to set learning goals, ability to manage time and learning management, ability to choose and apply learning strategies, ability to reflect on processes and evaluate learning outcomes, have learning motivation and responsibility, have learning initiative and creativity, and ability to communicate and collaborate.

In the Explain and Evaluate stages, encouraging self-reflection and self-assessment (Self-Reflection phase). Students compare what they find with what their friends find and with formal concepts. This is a metacognitive exercise in assessing one's own understanding. The “gamified” and visual nature of GeoGebra lowers the anxiety threshold. Students feel safe to "try out" (tinkering) because there is no risk of being permanently "wrong"; they can always click "undo". This psychologically safe environment is crucial for building self-efficacy. When students succeed in finding a pattern on their own through visual exploration, they build confidence ("It turns out I can!"). This belief is the main fuel for future learning independence.

These research results align with research by Hasibuan et al. (2023), who concluded that there is an effect of the Learning Cycle 5E model assisted by GeoGebra on students' mathematical problem-solving ability and mathematical learning independence. Additionally, these research results are consistent with research by Nuritha and Tsurayya (2021), who concluded that learning videos assisted by GeoGebra are effectively used as media or tools to help students in conducting mathematics learning that can improve student learning independence. These research results also align with research by Ishartono et al. (2022), who concluded that the improvement in learning independence of students who received the PBL model assisted by GeoGebra is better than students who received the expository model. It also aligns with research findings by Maharani et al. (2024), who concluded that the improvement in mathematical critical thinking ability and improvement in student learning independence applying the Discovery Learning model assisted by GeoGebra is better than students applying conventional learning models.

Student learning experiences were expressed in interviews with the experimental group for students with low, medium and high abilities, strengthening about (1) interesting things from the learning that took place, (2) obstacles in following the learning and difficulties in working on questions, and (3) suggestions for Learning Cycle 6E with Dynamic Geometry Software, namely GeoGebra. Students with low abilities said that learning through discussion adds to the fun atmosphere, but there is still a lack of cooperation in groups where students still rely on each other. The suggestion is that teachers should give questions to each student so that everyone can try to solve them, with a learning process that makes students active. Medium-ability students said that learning with IT can make them more interested in learning and is fun, but there are limited applications that don't support it so it takes longer to work on questions. The advice given is that learning should always use school infrastructure such as computer laboratories, not only at certain times, and learning is very appropriate if it is not only explained by the teacher but there is action from the students. Meanwhile, students with high abilities said that the learning carried out was more relaxed, and when doing assignments they were allowed to discuss or surf IT. However, when it comes to more complex problems it requires reinforcement from the teacher and when working on questions that require an application but are hampered by the cellphone they have. The advice given is that teachers should increase practice questions for students to discuss together and use school infrastructure for questions that require application. The next suggestion is that for other materials it is better to use the same learning model with discussions and the use of IT-based learning media.

This is in accordance with the Zimmerman Theory (2013), which states that students carry out self-judgment (assessing work results compared to standards/goals) and self-reaction (feeling satisfied/dissatisfied, attributing failure/success, adapting future strategies). Increased learning independence in students is not an innate trait, but a skill that can be trained. Learning Cycle 6E provides a practice cycle structure, while GeoGebra provides instant feedback that is crucial for self-monitoring. The challenge is to ensure students eventually internalize this cycle, so that they remain independent (able to plan, implement, and reflect) even when the Learning Cycle 6E and GeoGebra structures are no longer provided.

4. Conclusion

There is a significant difference in the improvement of mathematical communication ability between students who received the Learning Cycle 6E model assisted by Dynamic Geometry Software and students who received conventional learning, where the mean N-Gain of the Experimental group (0.62) is higher than the Control group (0.44). And there is a significant difference in the improvement of learning independence between students who received the Learning Cycle 6E model assisted by Dynamic Geometry Software and students who received conventional learning, where the mean N-Gain of the Experimental group (0.51) is higher than the Control group (0.26).

Limitations

This research focuses on improving mathematical communication skills and learning independence in marketing skills program students in linear function and quadratic function subject matter through the effectiveness of the Learning Cycle 6E model assisted by Dynamic Geometry Software as a digital use appropriate to students' times. It is hoped that future research can further demonstrate the effectiveness of the 6E Learning Cycle model assisted by Dynamic Geometry Software in developing other metacognitive abilities in different skill programs and more interesting subject matter.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this research. All stages of the research, development, implementation, and analysis were conducted objectively and independently, without any financial, professional, or personal interests influencing the results.

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