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Enhancing Students Performance on Graphing of Polynomial Functions Through Flowchart-Based Instruction

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ABSTRACT

This study examined the effectiveness of flowchart-based instruction in improving Grade 10 students' performance in graphing polynomial functions, particularly in determining degree, identifying the sign of the leading coefficient, and describing graph end behavior. A pretest-posttest quasi-experimental design was used with two intact classes at Balungao National High School in Pangasinan, Philippines. The control group ($n = 35$) received conventional teacher-led instruction, whereas the experimental group ($n = 35$) was taught through a structured flowchart that guided learners through successive decision points. A content-validated 30-item multiple-choice test was administered before and after the one-week intervention. Pilot testing yielded Cronbach's alpha coefficients of .802 and .921 for the assessment forms. Means, standard deviations, independent-samples t tests, and paired-samples t tests were used to analyze the data. The groups had comparable pretest performance ($M = 15.03$ and 15.54, respectively), $t = 0.490$, $p = .626$. At posttest, the experimental group obtained a higher mean score ($M = 22.54$, $SD = 4.10$) than the control group ($M = 18.77$, $SD = 4.05$), $t = 3.876$, $p < .001$. Both groups improved significantly; however, the experimental group's mean gain (7.00) was nearly twice that of the control group (3.74). The findings indicate that flowchart-based instruction can serve as an effective visual scaffold for organizing multi-step algebraic reasoning. Its use is recommended for concepts that require systematic interpretation, while longer and multisite studies are needed to establish broader generalizability.

Keywords: *flowchart-based instruction, polynomial functions, mathematics education, visual scaffolding, Grade 10*

INTRODUCTION

Mathematics education increasingly emphasizes conceptual understanding, reasoning, and the capacity to apply knowledge beyond familiar exercises. International assessment results continue to show large differences in learners' mathematical literacy, highlighting the need for classroom practices that move beyond the memorization of isolated rules (OECD, 2023). In the Philippine K to 12 curriculum, Grade 10 learners are expected to analyze polynomial functions and describe the behavior of their graphs. This competency requires students to connect symbolic features of a function with a visual representation, a transition that many learners find difficult.

Graphing polynomial functions is cognitively demanding because several ideas must be coordinated at the same time. Learners must identify the degree, determine whether it is odd or even, recognize the sign of the leading coefficient, and use these features to predict the direction of the graph as x approaches positive or negative infinity. Students may perform algebraic procedures correctly while still holding incomplete concept images of functions and graphs (Tall & Vinner, 1981). They may also rely on instrumental rules without understanding why the rules work, a distinction emphasized by Skemp (1976). Such difficulties can produce confusion among zeros, factors, roots, turning points, and end behavior (Al-Rababaha et al., 2020).

Visual scaffolds can make these relationships more explicit. A flowchart presents a process as an ordered set of decisions and outcomes. In polynomial graphing, it can direct learners to examine the degree first, classify its parity, identify the leading coefficient, and then select the corresponding end-behavior pattern. This organization is consistent with cognitive load theory because it reduces unnecessary demands on working memory and allows attention to be directed toward essential mathematical relationships (Sweller, 1988). It also reflects multimedia and dual-coding perspectives, which propose that coordinated verbal and visual representations can strengthen comprehension and retrieval (Mayer, 2001; Paivio, 1986).

Flowchart-based instruction also aligns with constructivist and scaffolded learning. Bruner (1966) argued that carefully sequenced representations can support learners as they progress toward more abstract understanding, while Vygotsky (1978) emphasized the value of guided support for tasks that students cannot yet complete independently. Research on diagrammatic self-explanation similarly suggests that structured visual representations can improve students' attention to relationships and support algebraic reasoning (Nagashima & Rittle-Johnson, 2021; Nagashima et al., 2022). Studies involving digital visualization and structured representations have also reported improvements in students' interpretation of functions and engagement in mathematics learning (Cahapay & Labrador, 2022; Chechan et al., 2023).

At Balungao National High School, classroom observations indicated that many Grade 10 students could recall formulas or isolated procedures but had difficulty explaining the end behavior of polynomial graphs. Learners frequently depended on memorized patterns and showed uncertainty when a polynomial was presented in an unfamiliar form. These difficulties suggested a need for a concise visual scaffold that could make the decision process visible and repeatable. A flowchart was therefore developed to guide students from the algebraic form of a polynomial function to an interpretation of its graph.

The study investigated whether flowchart-based instruction could improve students' performance in graphing polynomial functions. Specifically, it compared the pretest and posttest performance of a control group taught through conventional instruction and an experimental group taught through a flowchart-guided approach. It also examined between-group differences before and after the intervention and within-group changes from pretest to posttest. The study was guided by the expectation that the groups would begin at comparable levels and that the experimental group would demonstrate stronger post-intervention performance.

METHODS

Research Design

A pretest-posttest quasi-experimental design was employed. Two intact Grade 10 classes were used because individual random assignment was not feasible within the regular school program. One class served as the control group and received conventional teacher-led instruction, while the other served as the experimental group and received flowchart-based instruction. Both groups completed the same assessment before and after the intervention. Describing the design as quasi-experimental more accurately reflects the use of intact classes and the absence of random assignment at the individual level.

Research Locale and Participants

The study was conducted at Balungao National High School, a public secondary school in Balungao, Pangasinan, Philippines, during School Year 2025-2026. Seventy Grade 10 students participated. Grade 10 Eagle served as the control group (n = 35), and Grade 10 Canary served as the experimental group (n = 35). The two classes were selected because they followed the same curriculum, studied the same competency during the same period, and had comparable baseline performance. Other Grade 10 sections were not included because of scheduling and implementation constraints.

Instructional Intervention

The intervention was implemented for one week during regular Mathematics 10 classes. Both groups studied the same content: identifying the degree of a polynomial, determining the sign of the leading coefficient, and describing the end behavior of the graph. The control group received conventional instruction through explanation, board work, guided examples, and textbook exercises. The experimental group received the same curricular content through a flowchart that arranged the reasoning process into successive decision points. Learners first identified the degree, classified it as odd or even, determined whether the leading coefficient was positive or negative, and then followed the corresponding pathway to predict the left- and right-hand behavior of the graph. Practice tasks required students to explain the path used, rather than merely state an answer.

Research Instrument

A researcher-developed 30-item multiple-choice test was used as the pretest and posttest measure. The instrument assessed three areas: identifying the sign of the leading coefficient, determining the degree of a polynomial, and describing graph end behavior. A table of specifications aligned the items with the target Grade 10 mathematics competency and with cognitive levels involving recall, understanding, and application. Three mathematics education specialists, consisting of two master teachers and one head teacher, reviewed the items for relevance, clarity, age appropriateness, and curricular alignment. The instrument was pilot-tested with learners who were not included in the main study. Reported Cronbach's alpha coefficients were .802 for the pretest form and .921 for the posttest form, indicating acceptable to strong internal consistency.

Data-Gathering Procedure and Ethical Considerations

Permission to conduct the study was obtained from the school principal. Parents and students were informed about the purpose and procedures of the research, and participation was handled with attention to consent, privacy, and fairness. Student names were excluded from the encoded dataset. Both classes completed the pretest under comparable conditions. The instructional approaches were then implemented during the same school week, after which both groups completed the posttest. Tests were scored using the same answer key, and the results were encoded for statistical analysis. The intervention was delivered within the required curriculum so that no participant was denied access to the target content.

Statistical Analysis

Means, medians, standard deviations, variances, ranges, skewness, and kurtosis were initially used to describe performance. Independent-samples t tests compared the control and experimental groups at pretest and posttest, while paired-samples t tests examined change within each group. Statistical significance was evaluated at the .05 level. In reporting results, p values recorded as .000 in the original statistical output are presented as $p < .001$, consistent with journal reporting conventions. Because the study used intact classes, findings are interpreted as evidence of an instructional association within the study context rather than as unrestricted causal proof.

RESULTS AND DISCUSSION

Pretest and Posttest Performance

Table 1 presents the descriptive performance of the two groups. At pretest, the control group obtained a mean of 15.03 (SD = 4.27), while the experimental group obtained a mean of 15.54 (SD = 4.51). The difference of approximately half a point indicates that the classes began with similar levels of knowledge. At posttest, both groups improved, but the experimental group attained the higher mean. The control group's mean increased to 18.77 (SD = 4.05), whereas the experimental group's mean increased to 22.54 (SD = 4.10). The comparable posttest standard deviations indicate that the higher experimental mean was not produced merely by a small number of unusually high scores; performance shifted upward while remaining similarly dispersed.

Table 1. *Descriptive Performance of the Control and Experimental Groups*

Assessment	Group	n	Mean	SD	Median	Range
Pretest	Control	35	15.03	4.267	16.00	13
Pretest	Experimental	35	15.54	4.514	15.00	19
Posttest	Control	35	18.77	4.045	20.00	18
Posttest	Experimental	35	22.54	4.097	22.00	15

Note. Maximum possible score = 30.

The descriptive pattern supports the use of a visual decision pathway for a topic that requires several linked judgments. Students in the experimental group were repeatedly prompted to connect degree, parity, leading coefficient, and graphical direction. This sequence may have made the governing relationships easier to retrieve and apply. The result is consistent with cognitive load theory, which predicts that external organization can reduce unnecessary processing during multi-step problem solving (Sweller, 1988), and with multimedia learning, which emphasizes the value of coordinated visual and verbal information (Mayer, 2001).

Between-Group Differences

The independent-samples comparisons are shown in Table 2. The pretest difference was not statistically significant, $t(68) = 0.490$, $p = .626$. Accordingly, the null hypothesis of no pre-intervention difference was not rejected. This result provides evidence that the groups were reasonably comparable before instruction, although equivalence cannot be guaranteed in a study using intact classes.

Table 2. *Independent-Samples Comparisons at Pretest and Posttest*

Assessment	Control M	Experimental M	Mean Difference	t	p	Decision
Pretest	15.03	15.54	0.51	0.490	.626	Failed to reject H0
Posttest	18.77	22.54	3.77	3.876	< .001	Rejected H0

Note. df = 68 for both comparisons. Mean difference is presented as experimental minus control.

The posttest comparison showed a statistically significant difference in favor of the experimental group, $t(68) = 3.876$, $p < .001$. The 3.77-point difference represents approximately 12.6% of the 30-item test. Given the comparable pretest means, the posttest result indicates that the flowchart-supported class demonstrated stronger performance after the instructional period. The finding should nevertheless be interpreted within the boundaries of the one-week intervention and the use of two intact classes.

The result supports the theoretical expectation that learners benefit when abstract algebraic relationships are organized into visible steps. Rather than recalling four end-behavior cases as unrelated rules, students could identify the relevant features and follow a consistent reasoning path. This process encourages relational rather than purely instrumental understanding (Skemp, 1976). It also parallels evidence that diagrammatic self-explanation can improve attention to mathematical structure and support more deliberate algebraic reasoning (Nagashima & Rittle-Johnson, 2021; Nagashima et al., 2022).

Within-Group Learning Gains

Table 3 summarizes the paired pretest-posttest comparisons. The control group improved from 15.03 to 18.77, producing a mean gain of 3.743 points, $t(34) = 3.748$, $p = .001$. The experimental group improved from 15.54 to 22.54, producing a mean gain of 7.000 points, $t(34) = 7.636$, $p < .001$. Thus, both instructional approaches were associated with learning, but the experimental group's numerical gain was nearly twice the gain observed in the control group.

Table 3. *Paired Pretest-Posttest Comparisons Within Groups*

Group	n	Pretest M	Posttest M	Mean Gain	t	p
Control	35	15.03	18.77	3.743	3.748	.001
Experimental	35	15.54	22.54	7.000	7.636	< .001

Note. Paired-samples t tests; df = 34

The significant improvement of the control group is expected because it received regular instruction and practice on the target competency. Its progress shows that conventional teaching can produce learning during a focused lesson sequence. However, the larger experimental gain and the significant posttest difference suggest that the flowchart added instructional value by making the decision process more accessible. The visual pathway may have functioned as a temporary cognitive support, enabling students to reason through unfamiliar examples with less dependence on memorized phrases.

The findings are relevant to mathematics classrooms in which learners struggle to move between symbolic and graphical representations. Flowcharts are inexpensive, easy to reproduce, and compatible with printed, board-based, or digital instruction. They can also support teacher questioning: at each decision point, learners can be asked to justify why a branch is appropriate. This feature transforms the flowchart from a simple answer guide into a tool for mathematical explanation. Similar benefits have been associated with visual supports in Philippine mathematics instruction and with technology-supported representations of functions (Cahapay & Labrador, 2022; Chechan et al., 2023; Soso, 2020).

Several limitations temper the conclusions. The study involved only 70 students from one school, used intact classes, and lasted for one week. The researcher also implemented the intervention, which may have introduced expectancy or delivery effects. The assessment focused on a limited portion of polynomial graphing and measured immediate performance rather than long-term retention or transfer. Moreover, although the groups were comparable at pretest, stronger causal analysis would require random assignment or statistical controls such as analysis of covariance. Future studies should include additional schools, longer implementation periods, delayed posttests, and measures of students' reasoning processes and attitudes.

CONCLUSION

Flowchart-based instruction was associated with improved Grade 10 performance in graphing polynomial functions. The control and experimental groups began with comparable pretest scores, but the experimental group achieved a significantly higher posttest mean after the one-week intervention. Both groups improved, while the experimental group's mean gain was substantially larger. These results indicate that a structured visual pathway can help learners coordinate the degree, parity, leading coefficient, and end behavior of a polynomial graph.

The instructional value of the flowchart lies not merely in presenting an answer pattern but in externalizing the reasoning sequence. When teachers require students to explain each branch, the tool can reduce cognitive overload while promoting conceptual connections and mathematical language. Mathematics teachers may integrate flowcharts into lessons involving multi-step classification, procedural choices, or movement between symbolic and graphical forms. School-based professional development may also include the design and evaluation of concise visual scaffolds. Because the present findings are context-specific, further research should test the approach over longer periods, across varied learner groups, and with measures of retention, transfer, and independent reasoning.

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