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Research Article

Developing Students' Mathematical Critical Thinking Skills Using Open-Ended Questions and Activities Based on Student Learning Preferences

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This study has two parts: phase I designed activities to support all students' learning preferences, and phase II used open-ended questions and activities based on these preferences to develop students' mathematical critical thinking skills in polynomials at all performance levels (i.e., high-achieving, fair-achieving, and low-achieving students). This research used an embedded mixed-method design. The subjects selected were 28 out of 98 seventh graders at a boys' junior high school in Bangkok, Thailand, who were chosen by cluster random sampling technique. The instruments, which were validated by five experts, included a questionnaire, lesson plans, exit tickets, interview protocols, and tests of critical thinking skills in polynomials. The content validity was assessed via expert judgment, and reliability was assessed by item analysis. The quality and effectiveness of the instruments were acceptable. The research results showed the following: (1) most students at all performance levels prefer activities in which they can learn from participating in classroom activities, such as games, activities with real-life applications, and activities involving listening instead of reading and writing, and (2) critical thinking skills in high-achieving and fair-achieving students were at the fair level, while those of low-achieving students were poor. Analysis was the highest critical thinking subskill among high-achieving and low-achieving students, while interpretation was the highest subskill in among fair-achieving students. Open-ended questions and activities based on students' preferences appear to be practical for developing critical thinking skills among students of all achievement levels.

1. Introduction

The Thai government has set critical thinking as one of the key 21st-century skills in its National Education Plan [1] because they are essential for students' future success [2–5]. Critical thinking skills are necessary in the workplace [6–8] and can assist students in solving problems, making decisions, and managing their lives [9, 10]. According to Facione et al., critical thinking skills involve reasonable reflective thinking through the process of evaluation or judgment for interpretation, analysis, and inference using deductive and inductive reasoning to come to a decision about the problems considered [3, 11–14]. Students' critical thinking skills should be practiced in secondary school [15, 16].

According to international tests (PISA and TIMSS), Thai students have low critical thinking skills in mathematics. PISA (2018) reported that the students' average scores in Thailand are less than the OECD average scores, which means that students cannot model complex situations mathematically and select, compare, and evaluate appropriate problem-solving strategies for dealing with those situations [17]. TIMSS (2015) reported that secondary students' skills in mathematical concepts—including numbers, algebra, geometry, data analysis, and probability—are low. Secondary students also have some misconceptions about polynomials and make mistakes when adding and subtracting polynomials, representing signs incorrectly in complex problems. Such findings were also revealed in interviews with mathematics teachers who taught seventh graders for more than five years. Students also have some misconceptions in addition, subtraction, multiplication, and division [18–20], and it has been acknowledged that students need to develop critical thinking skills in mathematics [21].

Based on the country's primary core curriculum, Thai students must spend at least 6 hours a day in the classroom with teacher-centered learning, and students can be regarded as passive learners who listen and copy what has been written and said by the teacher [5, 22, 23]. Students might not learn efficiently because they have different learning styles [24–26], including the VARK sensory learning preferences (visual, aural, read/write, and kinesthetic) [26]. Several studies related to learning preferences have found that designed activities to support all student learning preferences can promote motivation and perception [27–30], and learning preferences could support students' achievement [30, 31]. High-achieving and low-achieving students have also been shown to have different learning preferences [32], although students can acclimate their learning preferences to new situations and find suitable ways to learn that content; the teacher therefore needs to prepare activities and tools that cover a diversity of learning preferences [33].

Mathematics is one of the subjects that is useful for developing students' critical thinking skills [34–38] because it involves reasoning, making decisions, and solving problems. Mathematical critical thinking skills involve the process of thinking and integrating knowledge of mathematics to solve mathematical problems using mathematical reasoning and problem-solving strategies [35, 39]. It has been suggested that instructional strategies develop critical thinking skills by allowing students to solve problems, using open-ended questions and providing various learning activities to engage students in solving those problems [38, 40]. Open-ended questions create meaningful learning opportunities by prompting children to reason and reflect while encouraging their use of language [41, 42]. Such questioning allows students to think actively and improve their problem-solving skills [43] because questions beginning with what, why, or how develop the abilities to interpret, analyze, evaluate, and make decisions and explain information based on reasoning [3, 34, 44–46]. Open-ended questions are thus practical for leading students to think critically based on their own knowledge and reasoning.

According to Firdaus et al., allowing students to solve open-ended questions related to daily life or their own experiences is an effective way to develop mathematical critical thinking skills and achievement among secondary students [35, 47]. Winarso and Hardyanti found that using open-ended questions can develop critical thinking skills in mathematics in low-achieving students [48]. The questions can also stimulate student participation [49, 50] and can elicit feedback on students' understanding and thinking [36, 51–53]. The developed critical thinking skills also affect student's performance differently, and high-achieving students can develop critical thinking skills in mathematics more easily than low-achieving students [54–57].

There are different components in measuring critical thinking skills in mathematics among high school students. Following Watson and Glaser, Aiyub et al. developed a five-part model for mathematical critical thinking problems: inference making, recognition of assumptions, deduction, interpretation, and evaluation of arguments [58]. Basri et al. followed Facione (2020) and identified six subskills: interpretation, analysis, evaluation, inference, explanation, and self-regulation [51]. Although Facione found six subskills for critical thinking, some studies have only considered four or five subskills. Sari and Caswita (2019) measured only interpretation, analysis, evaluation, and inference [59], while Seventika et al. developed mathematical critical thinking skills based on Facione, and Angelo's assessment considered five indicators: interpreting problems, analyzing the problem, applying the gained solution, evaluating the gained solution, and concluding the results attached with supporting evidence [56].

According to the observation, interviews with teachers, and review of measures for critical thinking skills in high school, the students in the studied school need to improve their critical thinking skills in interpretation, analysis, evaluation, and inference, so the researchers focused on four subskills, which are fundamental to critical thinking according to Facione, because this targeting was considered suitable for students' critical thinking skills in the polynomials course.

This study proposed an intervention involving open-ended questions and activities based on student learning preferences, which aims to (1) study and classify the classroom activities that support students' learning in mathematics and (2) develop students' mathematical critical thinking skills at the different performance levels in polynomials that focus on the four subskills of interpretation, analysis, evaluation, and inference.

2. Materials and Methods

2.1. Research Design and Sampling. After obtaining permission from King Mongkut's University of Technology Thonburi Board (KMUTT-IRB-COA-2021-007), the study was implemented with an embedded mixed-method design from April to May 2021 at a high school in Bangkok, Thailand. The participants were 98 seventh-grade students (three classes) in their second semester. Before the classes were selected, researchers analyzed the homogeneity of variance and the equality of means of students by mathematics scores from the first semester. The variance for the three classes was equal ($0.94 > 0.05$), and the mean difference did not statistically significantly differ at the 0.05 level ($0.56 > 0.05$). Because these three classes were not statistically different, one class of 32 students was chosen as a sample. However, due to missing data, some students needed to be omitted, so the sample size fell to 28 students, who were divided into three groups: high achievement, fair achievement, and low achievement.

2.2. Procedures. The content of the instruction used for this study involved the addition, subtraction, multiplication, and division of the polynomials. The researchers collected data in two phases. In Phase I, the researchers employed Google Forms to collect students' demographic data and mathematics scores in the first semester, as well as the activities in which students prefer to participate. The data about developing critical thinking skills in polynomials were collected in Phase II; the data on activities that supported student learning preferences were obtained from the students' responses in Phase I and were employed in designing the lesson plans. The intervention took place over 12 periods (two periods/week). Each student sat at a single desk typically arranged in rows and columns. When doing pair or group work, students occasionally shifted their desks to work together. Before finishing the class, students were given exit tickets to give learning feedback. Students were given a pretest before the intervention began, and a posttest was given after completing the interventions. Five students were selected by convenience sampling for interviews about the polynomial questions to observe students' mathematical critical thinking skills during the fifth and eleventh periods. Table 1 shows the teaching process.

The sample activity is one example of the open-ended activities to support student learning preferences to develop the targeted critical thinking subskills (see Figure 1). In this example, students were divided into groups of four to solve the problem. "This is a set of jigsaws that represent the field of Abang's farm, which includes a strawberry field, a tomato field, a cabbage field, and a garlic field. I would like to create two ditches on the farm that make in the letter T. Abang told me that "*the area and perimeter of each ditch are the same*" Do you believe him? Why?"

An excerpt taken from a typical lesson is given below. "T" represents the teacher, and "S" represents the students. The excerpt contains the open-ended questions in the discussion section after students solved the problem with their group (see Table 2).

2.3. Instruments. In Phase I, the instrument comprised an item with open-ended questions "*What kind of classroom activities are suitable for you and support your learning? State your reason.*" to obtain critical information for developing the lesson plans. In Phase II, the researchers developed a critical thinking skills test in polynomials to determine how the intervention affected students' skills. The test consisted of nine multiple-choice items with five options to measure interpretation and analysis in polynomials and two essay items to measure evaluation and inference. Exit tickets were used to obtain students' feedback. The questions in the exit ticket are as follows:

(1) "Did today's activities help you learn? Why?"
(2) "Do you think you think more carefully than before when you learn in my class? Why?"

The structured interview on polynomials was used to observe the development of critical thinking subskills during treatment in the fifth and eleventh periods. The questions used in the interview were as follows:

(1) "*Multiplication between a monomial and a polynomial can be illustrated by finding the area of a rectangle.*" Do you agree with this statement?
(2) Do you think your friends would answer this question the same as you did or differently? Why?

The content validity of the instruments was assessed by five experts in mathematics, mathematics education, and measurement/evaluation in education. All of the instruments were then revised based on the experts' opinion. The item-objective congruence was 0.60–1.00. After instrument validation, the skills test and structured interview prompts were pilot tested by 30 eighth graders in the same junior high school, and the results were analyzed. The difficulty index ranged between 0.25 and 0.79, discriminative power ranged between 0.25 and 0.75, and the reliability verified through Cronbach's alpha was found to be 0.65. Table 3 illustrates the common components of the questions that provide an opportunity to think critically about polynomials.

2.4. Data Analysis Techniques. The content analysis technique was used to analyze the qualitative data obtained from the responses about student learning preferences, experts' and eighth-graders' suggestions from the pilot testing, feedback from the exit tickets, and interview results. For the quantitative data, pre- and post-test results were analyzed with normal distribution using the Shapiro–Wilk test, which suggested a normal distribution, as the significant value must be more than 0.05. Second, the hypothesis about the development of critical thinking skills related to polynomials among seventh graders was tested using the dependent *t*-test and descriptive statistics, such as means, standard deviations, and percentage. Data from the test were analyzed by calculating percentages to assess the level of critical thinking skills following Firdaus et al. (2015), as shown in Table 4.

3. Results

3.1. Quantitative Data. The Phase I results in Table 5 show that 11 low-achieving students, 7 fair-achieving students, and 3 high-achieving students preferred to participate in fun learning activities that can be applied in daily life, as well as engaging with teachers who understand the students. There were four low-achieving students and one high-achieving student who preferred speaking and listening activities. One low-achieving student preferred visual activities, and another low-achieving student preferred reading/writing activities.

For Phase II, Table 6 shows the means and standard deviations for low-achieving students' mathematical critical thinking subskills; before treatment, interpretation ($M = 0.647$, $SD = 0.786$) and analysis ($M = 1.941$, $SD = 1.197$) were poor, and evaluation ($M = 0.353$, $SD = 0.606$) and inference ($M = 0.353$, $SD = 0.786$) were very poor. After treatment, interpretation ($M = 1.118$, $SD = 1.054$) and inference ($M = 1.529$, $SD = 1.586$) were poor, and analysis ($M = 2.588$, $SD = 1.698$) and evaluation ($M = 1.235$, $SD = 1.091$) were fair. Overall, the critical thinking skills

Table 1: Outline of the teaching process.

Time in minutes	Process of teaching using open-ended questions	Instruments or activities to support students' learning preferences
5	Introducing the session by showing the problems or reviewing the previous knowledge of polynomials	(1) Visual supported (i) Symbol of algebra tiles
15	Conducting the activities that are related to their daily life (i) Individual work (ii) Pair/group work	(ii) Highlight the necessary things (iii) Flashcards (2) Aural supported
15	Discussion of the results	(i) Open-ended questions
10	Students and teachers help to summarize	(ii) Think/pair/share activities (3) Read/write support (i) Worksheets (ii) Flashcards (4) Kinesthetic supported (i) Algebra tiles to explain the polynomials
5	Students complete the exit ticket	*Activities to support all learning preferences (i) Bingo (ii) Roleplaying as a teacher to determine the correctness of given solutions (iii) T puzzle *When summarizing, using Wonder Go or Kahoot

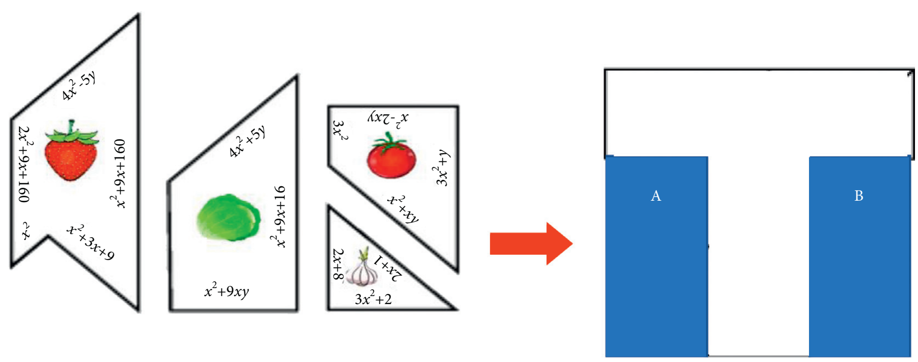

Figure 1: Illustration of sample activity.

(from the mean of the four subskills) among low-achieving students in the posttest remained poor.

Table 7 shows the means and standard deviations for fair-achieving students' mathematical critical thinking subskills. Before treatment, interpretation ($M = 1.143$, $SD = 0.900$) and analysis ($M = 1.429$, $SD = 1.272$) were poor, and evaluation ($M = 0$, $SD = 0$) and inference ($M = 0$, $SD = 0$) were very poor. After treatment, interpretation ($M = 1.857$, $SD = 1.069$) was good, analysis ($M = 3.571$, $SD = 1.397$) and evaluation ($M = 1.571$, $SD = 0.787$) were fair, and inference ($M = 1.857$, $SD = 0.900$) was the only subskill at the poor level. Overall, the critical thinking skills among fair-achieving students in the posttest improved from poor to fair.

Table 8 shows the mean and standard deviations for high-achieving students' mathematical critical thinking subskills. Before treatment, interpretation ($M = 0.250$, $SD = 0.500$), evaluation ($M = 0.500$, $SD = 0.577$), and inference ($M = 0.250$, $SD = 0.500$) were very poor. Analysis ($M = 2.500$, $SD = 1.291$) was the only subskill at the poor level. After treatment, all subskills were fair. Overall, the critical thinking skills among high-achieving students in the posttest improved from very poor to fair.

Table 9 shows that the increase in pre- and post-test scores among low-achieving students is 4.734, and the t-test showed a significant difference in mean improvement between pre- and post-test scores among low-achieving students (Sig. < 0.05). The increase from pre-test to post-test scores among fair-achieving students is 6.286, and the t-test showed a significant difference in mean improvement (Sig. < 0.05). The increase in pre-test and post-test scores among high-achieving students is 6.000, and the t-test showed a significant difference in the mean improvement (Sig. < 0.05). The results indicate that students' performance improved after the use of open-ended questions and activities based on student learning preferences.

3.2. Qualitative Data. Five students participated in 1-on-1 interviews, and the researcher noticed that all students at different performance levels were guided by the "*What do you see in the picture*?" activity (Figure 2) to practice interpreting and reasoning. In the second interview, there were four out of five students—two high-achieving students, one fair-achieving student, and one low-achieving student—who could analyze and solve the problem based on

Table 2: Use of open-ended questions in intervention.

Critical thinking subskills	Example of open-ended questions in polynomials session
Interpretation	T: what do the polynomials in each jigsaw mean? S: the polynomials represent the length of that side of the field.
Analysis	T: Abang said that "*the area and perimeter of each ditch are the same.*" Do you believe him? S: no, I don't. T: why? S: the area of the ditch A is $4x^4 + 36x^3 + 64x^2$, but the area of the ditch B is $3x^4 + 27x^3 + 50x^2 + 18x + 32$. Therefore, my friends and I found that the area of the ditch A is different from the ditch B.
Evaluation	T: how do you know that is true, since we don't even know the value of x? S: my friend and I tried to substitute positive integers, the area of ditch B more than the area of ditch A because ditch B has more expression terms.
Inference	T: are both perimeters equal? How do you know that? S: if I substituted x by 1 and 2, then the perimeter of the ditch A is less than that of ditch B. However, if I replaced x by 3, the perimeter of the ditch A is greater than that of ditch B. Therefore, the value of x that can equalize the perimeter should be somewhere between 2 and 3.

Table 3: Sample test question.

Sample question of the test to develop critical thinking skills in polynomials				
Consider the statements in each item below. Which do you think is the correct answer?				
(a) $((4x^2 - 15x)/-x) = 4x - 15x = -9x$		(b) $((-4x^2 - 15x)/-x) = 4x + 15$	(c) $((-4x^2 + 15x)/-x) = -4x - 15$	
(1) a	(2) b	(3) c	(4) All of these above	(5) None

Table 4: Score range for rating mathematical critical thinking skills [35].

Range of score %	Students' critical thinking skills
80–100	Excellent
60–79	Good
40–59	Fair
20–39	Poor
0–19	Very poor

the picture, as well as being able to predict what their peers' answers would be based on their learning. However, there was only one low-achieving student who understood the basic knowledge and could only answer the teacher's guided questions; when asked to solve the problem individually, the student could not apply the knowledge learned in the class. According to the observation, there was a big difference in behavior in the first and second 1-on-1 interviews. Students were encouraged to express their opinions, and although the five students were at three different performance levels, we observed that they tried their best to answer and give their reasons based on what they had learned.

Table 10 shows excerpt taken from the interview results. "T" represents the teacher, "H" represents high-achieving students, "F" represents fair-achieving students, and "L" represents low-achieving students.

The data obtained from the exit tickets indicate that fun activities and instruments adjusted to students' learning preferences could help students at all performance levels participate in mathematics class. Additional data are shown below.

> Low-achieving 2: "Yes, it can help us because a teacher had a game inserted, and a mobile phone came in for us to use in the class. Because we are modern, we must keep up with technology, unlike other teachers who use only books."
>
> Low-achieving 4: "Yes, because you can make me understand."
>
> Fair-achieving 2: "Yes, it can help me apply knowledge to consider daily life skills."
>
> Fair-achieving 3: "It helped me to learn to understand because I can use my smartphone to learn with your activity."
>
> High-achieving 1: "Yes, because it is more fun than just watching a teacher speak for 50 minutes straight; I think it is enjoyable."
>
> High-achieving 2: "It helped me understand monomials using the Algebra tile visual tools quickly."

In addition, the teaching process could help them think carefully before making judgments because the open-ended questions challenged them. The following are some of the students' answers.

> High-achieving 3: "Yes, because when I have studied the monomial, it was challenging and complex, but it made me think more carefully when the teacher used more questions than before."
>
> Fair-achieving 3: "Yes, I think about being more careful about the activity."
>
> Low-achieving 6: "Yes, because the teacher's activities tricked me every class."
>
> Low-achieving 9: "Yes, because the teacher's activities made me think more carefully, because it is complex."

Table 5: Number of students at different performance levels and learning preferences.

Preferred activities (content analysis)	Student performance levels			Preferences
	Low	Fair	High	
(1) Students who like to participate in fun learning activities that can be used in life with teachers who understand the students. "*I love the activities that are like a game.*" "*I love the activities that involve competition.*" "*I love hands-on activities.*" "*I love exciting classes, fun activities.*" "*I would like fun activities and a teacher who understands me.*" "*I love a teacher who instructs by using fun activities relevant to daily life.*"	11	7	3	K
(2) Students who like to speak and listen in the class. "*I love to listen to everything that the teacher explains.*" "*I love to speak and share my ideas in class.*" "*I love the teacher who explains content clearly.*"	4	0	1	A
(3) Students who like to watch from the symbols, colorful letters, graphs. "*I love to see the symbols that make me easy to understand.*"	1	0	0	V
(4) Students who like to read and write from the textbook, worksheet. "*I love to read from the book.*"	1	0	0	R

Table 6: Low-achieving: means and standard deviations for and pre- and post-test scores.

Critical thinking subskills	*N*	Maximum score	Pretest		Posttest	
			Mean	SD	Mean	SD
Interpretation	17	3	0.647 (21.569%)	0.786	1.118 (37.255%)	1.054
Analysis	17	6	1.941 (32.353%)	1.197	2.588 (43.137%)	1.698
Evaluation	17	3	0.353 (11.765%)	0.606	1.235 (41.176%)	1.091
Inference	17	6	0.353 (5.882%)	0.786	1.529 (25.490%)	1.586
Overall	17	18	2.701 (15.010%)	1.993	6.760 (37.556%)	4.002

Table 7: Fair-achieving: means and standard deviations for pre- and post-test scores.

Critical thinking subskills	*N*	Maximum score	Pretest		Posttest	
			Mean	SD	Mean	SD
Interpretation	7	3	1.143 (38.095%)	0.900	1.857 (61.095%)	1.069
Analysis	7	6	1.429 (23.810%)	1.272	3.571 (59.524%)	1.397
Evaluation	7	3	0 (0%)	0.000	1.571 (52.381%)	0.787
Inference	7	6	0 (0%)	0.000	1.857 (30.952%)	0.900
Overall	7	18	2.571 (14.286%)	1.718	8.857 (49.206%)	3.024

Low-achieving 10: "Yes, because the teacher has activities that made me think."

Low-achieving 11: "Yes, because the worksheets made me be careful before answering the question."

4. Discussion

Based on the results from Phase I, as shown in Table 5, most students at all performance levels dislike visual and reading/writing activities because they are generally accustomed to learning via a teacher-centered approach, in which the main activities are writing, listening, and watching the teacher's instruction, with less interaction between students and teacher. According to the information obtained from the exit tickets, during the intervention, students had more interaction and enjoyment in the classroom than in traditional classroom management settings. These findings are supported by the suggestions of Khongpit et al. that the teacher should design a variety of activities to appropriately support student learning preferences and encourage student participation [28, 29, 31]. Tan found that many students prefer a teacher-centered approach, but in this study, students did not prefer teacher-centered methods, but they did have distinct learning styles in class [33]. Phantharakphong found that high-achieving students tend to prefer activities that involve learning by doing and apply to daily life, while low-achieving students tend to prefer a variety of activities that include visual, speaking, and listening activities, as well as writing activities [32]. In the present study, however, low-achieving students also preferred activities normally favored by high-achieving students.

Table 8: High-achieving: means and standard deviations for pre- and post-test scores.

Critical thinking subskills	N	Maximum score	Pretest		Posttest	
			Mean	SD	Mean	SD
Interpretation	4	3	0.250 (8.333%)	0.500	1.500 (50.00%)	0.577
Analysis	4	6	2.500 (41.667%)	1.291	4.000 (66.667%)	0.816
Evaluation	4	3	0.500 (16.667)	0.577	1.500 (50.000%)	1.291
Inference	4	6	0.250 (4.167%)	0.500	2.500 (41.667%)	3.000
Overall	4	18	3.500 (19.444%)	2.517	9.500 (52.778%)	4.123

Table 9: Dependent t-test on critical thinking skills of students at all performance levels.

Period	N	Maximum score	Difference between pre- and post-test scores	Standard deviation	t	p
Pretest-posttest of students at low performance	17	18	4.734	3.940	4.955	0.000*
Pretest-posttest of students at fair performance	7	18	6.286	3.946	4.214	0.006*
Pretest-posttest of students at high performance	4	18	6.000	2.828	4.243	0.024*

* $p < 0.05$.

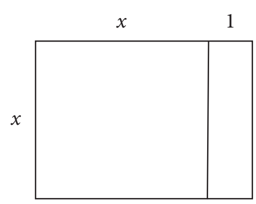

Figure 2: Illustration for a question used in the interview.

According to the descriptive analysis, inferential analysis, and interview results in Phase II, the level of students' critical thinking subskills (interpretation, analysis, evaluation, and inference) at all performance levels had improved after the intervention using open-ended questions and activities based on student learning preferences. These findings are supported by Plianrama et al. that open-ended questions can help to develop mathematical critical thinking skills [34, 47, 48].

Students at all performance levels can positively develop critical thinking skills in solving polynomials problems, by practicing decision-making based on reasoning and experience to find appropriate answers. Students require various activities to aid learn in with teacher support; having the opportunity to choose how to learn is a benefit to students, which is in line with Tan, who found that students can adapt and choose appropriate ways to learn in class [33]. It is also supported by Singweratham and Munroe, who found that activities provide an environment conducive to learning that encourages students to seek and build knowledge on their own through cooperation and interaction with peers [30, 53]. The open-ended questions and activities in the present intervention taught students how to think with mathematics beyond memorization. These results are in line with Su et al., as the process of thinking through math helps students think critically, discover relationships and patterns of mathematical content, innovate, and create new ideas [36]. The results shown in Table 9 illustrate that the critical thinking skills of the high- and fair-achieving students were at the same level after the intervention, which is a novel finding, as Zetriuslita et al. found that students at different performance levels tend to develop critical thinking skills to differential levels; that is, the high-achieving students can have the potential to develop the highest level of critical thinking skills [54–57].

Results for each subskill, shown in Tables 6–8, indicate that analysis yielded the highest level among high- and low-achieving students. According to Firdaus et al., teachers should allow students to explore and plan to solve problems related to their daily life. The highest scores for fair-achieving students were found for interpretation because, in this study, open-ended questions were used with pictures or visual aids to support interpretation [35, 56]. According to Aziza et al., students practice identifying problems, determine and map what is known, and, after being guided by the use of questions, can visualize the problem [50, 53, 56]. However, the results also show that the lowest critical thinking subskill for the students at the three different performance levels is inference, which is in line with Basri et al. [51, 56].

Critical thinking skills are essential for secondary students because they face related problems in their daily life. This is in line with Facione et al.'s belief; that is, critical thinking is both an academic and a life skill [3, 48]. Using open-ended questions and activities based on student learning preferences is thus one of the instruction methods best suited to preparing secondary students to meet the demands of the 21st century. Although the open-ended questions and activities based on student learning preferences developed students' critical thinking skills at all performance levels, this study has limitations. First, only male students participated in this study. Second, the research instrument focused on mathematical critical thinking skills related to polynomials using only four subskills, so future studies could consider a different range of subskills. We also

Table 10: Interview results.

Critical thinking subskills	Interview transcripts		
	(1) First interview at period 5		
Evaluation (question 1)	T: "Multiplication between a monomial and a polynomial can be illustrated by finding the area of a rectangle." Do you agree with this statement?		
	All were students silent for more than 10 seconds		
Interpretation	T: what do you see in the picture?		
	H: I see rectangles, variables, and numbers.	F: I see algebra tiles.	L: I see a monomial.
Analysis	T: can you explain more how it is related to our points?		
	H: the width is represented by a monomial, and the height is represented by a polynomial.	F: it has a variable x and 1.	L: the picture has an x and a 1.
Evaluation	T: so, do you agree that finding the area of a rectangle can be used to demonstrate multiplication between a monomial and a polynomial? Why?		
	H: yes, I do, because the expression of the width is a monomial, and the expression of the height is a polynomial. I think the statement is false because both expressions are monomials.	F: no, I don't, because we cannot use monomials to find the area of rectangle.	L: no, I don't. (Silent and smile)
Inference (question 2)	T: do you think your friends would answer this question (question 1) the same as you or different? Why?		
	H: I think, the same as me.	F: i think, the same as me.	L: I think they will answer it as monomials and think like me.
	2. Second interview at period 11		
Evaluation (question 1)	T: "Multiplication between a monomial and a polynomial can be illustrated by finding the area of a rectangle." Do you agree with this statement?		
	H: yes, I do.	F: of course, yes.	L: yes, I do.
Interpretation and analysis	T: why?		
	H: it related to some of the formulas. T: the formula of what? H: the formula of the area of the rectangle. T: how it related to our point? H: i think the rectangle's width and height, respectively, are represented by a monomial and a polynomial.	F: in order to find the area of the rectangle, I just multiply between a monomial and a polynomial in this picture (Figure 2).	L: (Think more than 10 seconds) it could be $x\ (x+1)$. T: what do you mean by "it could be $x\ (x+1)$"? L: (Silent) T: what does x represent in the picture? L: I think it represents the width of the rectangle.
Inference (question 2)	T: do you think your friends would answer this question (question 1) the same as you or different? and why?		
	H: yes, I think my friends would answer similarly to me because the length of the rectangle times the width of the rectangle. This is the general formula.	F: yes, I think the answer should be the same way, because my friends should know the formula for finding the area.	L: I think I'm not sure. T: why are you not sure? L: because each person has their own way of thinking.

recommend that future studies include female students and replicate the present study to allow comparison in the use of open-ended questions and activities based on student learning preferences, as well as traditional teaching approaches, for students at different performance levels. The use of open-ended questions and activities based on student learning preferences could also be used for instruction in different mathematics topics.

5. Conclusions

Open-ended questions and activities based on student learning preferences can help in developing students' critical thinking skills related to polynomials at all performance levels. Students tended to prefer activities that allowed them to learn by practicing and that involved discussion more than reading/writing and visual activities. However, this study did not assess all critical thinking subskills, so subsequent research could seek to determine all critical thinking subskills among secondary students and increase the sample using open-ended questions and activities based on student learning preferences.

Data Availability

The data are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they do not have any conflicts of interest regarding the publication of this paper.

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