Types of Students' Errors in Tangent: Effect of Technology

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Abstract: Many studies identify trigonometry as a challenging topic for teachers, preservice teachers, and students. Understanding these challenges is essential for educators to develop effective strategies. Borasi (1987) emphasized that learners' errors can be used to identify learning challenges and guide remediation. This study aims to explore students' challenges in learning the concept of tangent, the types of errors they make, and the impact of technology interventions, particularly Python programming, on their learning outcomes. This study utilized the Categories of Errors defined by Movshovitz-Hadar et al. (1987) to analyze 10th-grade students' errors before and after the intervention. The results showed that the number of technical errors significantly reduced after the intervention. Also, this study provides a qualitative analysis of the common mistakes students make when answering tangent-related questions.

Keywords: Tangent, students errors, trigonometry, technology

1. Introduction

Difficulties in trigonometry have been documented at both high school and college levels across various regions worldwide (Dewanto et al., 2017; Faturohman & Amelia, 2020; Nabie et al., 2018; Rohimah & Prabawanto, 2019), and many studies identify trigonometry as a challenging topic for both mathematics teachers, preservice teachers, and students (Faturohman & Amelia, 2020; Nabie et al., 2018; Yusha'u, 2013). Thus, understanding these challenges is crucial for educators to develop effective teaching strategies. Borasi (1987) mentioned that learners' errors can be a powerful tool to identify learning challenges, hypothesize their possible causes, and direct educators to find remediation. Teachers need to focus on the misconceptions faced by their students in their teaching activities (Chua et al., 2016). Borasi (1987) also suggested that "errors can be used as a motivational device and as a starting point for creative mathematical explorations, involving valuable problem solving and problem posing activities" (p. 7). This study aimed to investigate students' challenges in learning the concept of tangent in trigonometry, the types of errors they make in solving questions, and explore the effect of technology interventions, using Python programming, on their learning outcomes in this concept.

1.1. Research Questions

This study aimed to investigate the types of errors students make in solving trigonometry questions and the effect of using Python programming on their learning. Thus, this research aims to answer the following questions:

1. What are the most common types of errors made by learners in the tangent concept in trigonometry?
2. How does a specific teaching intervention, Python programming, affect the types of errors students make?

1.2. Literature Review and Theoretical Perspective

Several studies have identified types of misconceptions and difficulties students encounter when solving trigonometry questions. In their study of 189 vocational high school students, Dewanto et al. (2017) found that students' errors included understanding the meaning of the problem, applying the concept, and calculating. A study by Fahrudin and Pramudya (2019) on 203 students' answers to trigonometry questions concluded that common errors were data errors, concept errors, strategy errors, calculation errors, and conclusion errors. Rohimah and Prabawanto's (2019) study showed that students' difficulties in solving trigonometric equations included factoring in the form of trigonometric quadratic equations, using basic trigonometric equations, and performing algebraic calculations/computations. The results of the study by Arhin and Hokor (2021) on 90 high school students revealed that most errors occurred at the transforming, processing, and encoding stages. They also found that students particularly struggled with the application of trigonometry in real-world scenarios (Dewanto et al., 2017; Fahrudin & Pramudya, 2019). Based on the findings of these studies and to understand and categorize the types of errors our students made, we used Movshovitz-Hadar et al., (1987) theoretical frameworks that will be explained in the next section.

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1.3. Conceptual Framework

This study relied on the model provided by Movshovitz-Hadar et al., (1987) and in categorizing the incorrect answers to the pre and post-test questions. The model developed by Movshovitz-Hadar et al. (1987) categorized the types of errors students can make when answering math questions into six categories. These six categories include misused data, misinterpreted language, logically invalid inference, distorted theorem or definition, unverified solution, and technical errors. Table 1 shows a description of errors and an example for each category.

Table 1. Categories of Errors Defined by Movshovitz-Hadar et al., (1987).

Category	Description of the Type of the Error
Misused data	Errors that can be related to some discrepancy between the data as given in the item and how the examinee treated them. Such an error may be committed either initially while putting the data together or later while processing the data.
Misinterpreted language	Errors that deal with incorrect translation of mathematics described in one language (possibly symbolic) to another (possibly symbolic)
Logically invalid inference	Errors that deal with fallacious reasoning and not with specific content.
Distorted Theorem or Definition	Errors that deal with a distortion of a specific and identifiable principle, rule, theorem, or definition.
Unverified Solution	Errors in this category is that each step taken by the examinee was correct in itself, but the final result as presented is not a solution to the stated problem.
Technical Errors	This category includes computational errors.

2. Method

This study was conducted during the spring semester of the 2023-2024 academic year in a vocational school in Iran.

2.1. Subject

The research subjects were trigonometric ratios, tangent and its application in the real world, for tenth-grade students in the second semester of the school year in Spring 2024. Before participating in the study students already learned about this concept in the first semester in Fall 2023 in chapter two of the test book (nationally used textbook) was obtaining trigonometric ratios of different angles, especially 30°, 45° and 60°, by using the definition of trigonometric ratios. Moreover, this chapter included questions about the use of these trigonometric ratios in real problems, such as getting the height of the ladder attached to a house.

2.2. Participants

Participants of the study were 37 students agreed to participate in the study. Out of 37 students who answered the pretest questions 7 of the students opted to not answer the post-test questions or were absent on the post-test day. The study was conducted in one class and students worked in two groups, experimental and control groups, during the intervention period.

2.3. Data Collection

Data collected for this study consisted of participants’ answers to pretest and post-test questions. The pretest included eight questions about drawing angles, the theorem of similarity of triangles, calculating the tangent of an angle, drawing an angle with a specific tangent, and determining whether a trigonometric equation is correct. The post-test included five questions about drawing a specific angle and calculating its tangent, three real-world questions, and finding the tangent of a 37.2° angle. In finding the tangent of 37.2°, the control group was asked to use a right triangle and compare it with the answer from a calculator, while the experimental group was also asked to compare the answer with the result from Python.

2.4. Intervention

Students in the control and experimental groups were divided into seven groups of two or three members to work collaboratively. The control group had two sections using lectures based on the textbook to review the concept of tangent. The same review was done in the experimental group, along with teaching how to find the tangent of different angles in Python and using the triangle designed in GeoGebra by the authors. The purpose of teaching Python was not for them to master programming, but to observe how using different tools, which give different answers, affects their answers to the questions. See the picture of the used activities in Figure 1.

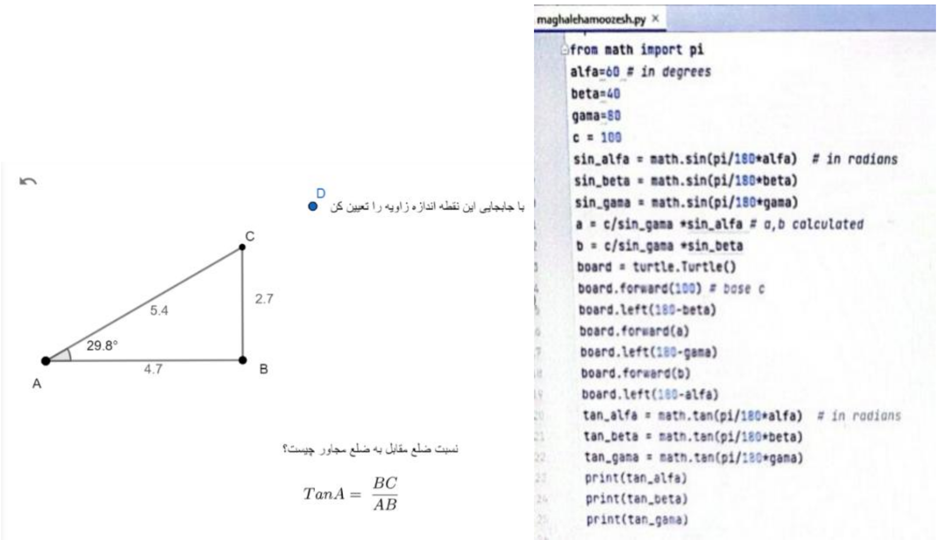


Figure 1. Class Activities in experimental group.

2.5. Data Analysis

For the data analysis, we first checked the number of correct, incorrect, or unanswered questions in both the pretest and post-test. We then applied the model by Movshovitz-Hadar et al. (1987) to categorize students' errors. To ensure consistency in interpreting the types of errors, we selected three random sets and individually categorized their answers for questions 4, 5, 6, and 7 in the pretest, resulting in a total of 12 questions. We assessed the percentage of agreement as an indicator of inter-rater reliability. Upon reviewing the categories, there was a 75% agreement between the authors. Based on the discussion in this meeting, we agreed to use a single code for each question to ensure consistency. Similar to Movshovitz-Hadar et al. (1987), only the first error was marked in each incorrect answer. Additionally, we introduced an "incomplete" category to their framework to classify answers that demonstrated a few correct steps but were unfinished or lacked the final answer.

The authors then coded all the pretest and post-test questions separately and created two different tables individually. They reviewed all the questions to ensure they had consistent codes for each one. For the coding of questions 4 and 5 in the pretest, which were about the similarity of triangles and the similarity of two right-angle triangles, we decided to mark an answer as correct if the student referred to either the equality of corresponding angles and the proportionality of corresponding sides or the triangle similarity criteria, such as AA (Angle-Angle) or SSS (Side-Side-Side).

3. Results

This section is divided into two parts: the results of the pretest and the results of the post-test. Each part will first present statistics on the number of correct and incorrect answers in tables. Then, the analysis of the types of student errors based on the Movshovitz-Hadar et al. (1987) framework will be displaced. Additionally, there will be further elaboration and observations on the Students' common errors.

3.1. The Results of the Pretest

Table 2 shows the number and percentage of the correct and incorrect answers in the Pretest.

Table 2. The Number of Correct, Incorrect, and No-answer Responses in the Pretest.

Question Number =>	1	2	3	4	5	6	7	8	Total
Correct	33	32	15	10	11	24	6	15	141
Percent	100%	97%	45%	30%	33%	73%	18%	45%	53%
Incorrect or Incomplete	0	0	3	22	20	9	13	15	82
Percent	0%	0%	9%	67%	61%	27%	39%	45%	31%
No Answer	0	0	15	1	2	0	14	3	35
Percent	0%	0%	45%	3%	6%	0%	42%	9%	13%

As Table 2 shows 53% of all students' answers were correct, 31% of the answers were incorrect or incomplete, and 13% of the questions were not answered by students. All participants' answers to question one (drawing an acute angle) and part one of question two (drawing a right angle) were correct, and only one student could not draw a 45° angle (part two of question two); the given angle was less than half of a right angle. Question six (finding the tangent of the 30° angle) was the other question that students could answer correctly (73% of the students answered correctly), However, interestingly, none of the students' answers for question seven (finding an angle whose tangent is equal to 3) were correct. For all other questions, less than half of the students' answers were correct.

Around ⅓ of the students' answers for question four (definition of similarity of triangles) and question five (similarity of right angle triangles) were correct. More than half of the students' answers to question three (about finding the length of the right triangle with a diagonal of root 2) were incorrect or not answered. In identifying the correctness of an equation relating the tangent of 30° to the tangent of 60°, less than half of the students (45%) provided correct answers.

Type of Students' Errors in Pretest

Since there were no errors in questions one and two, the authors did not include these two questions in the table. Questions three, four, and five were related to the students' background knowledge of the concept, while questions six, seven, and eight were related to using the concept to solve a problem. Therefore, the authors used a separate table for these questions. Table 3 shows students' errors in the pretest for questions three, four, and five.

Table 3. Type of Students' Errors in Three First Questions Based on the Movshovitz-Hadar et al., (1987).

		Type of Errors						
		Misused Data	Misinterpreted Language	Logically Invalid Inference	Distorted Theorem or Definition	Unverified Solution	Technical Errors	Total Incorrect
Q 3	Number of Students	1		1				2
	Percentage	50%		50%				
Q 4	Number of Students				19			19
	Percentage				100%			
Q 5	Number of Students				16		0	16 *
	Percentage				88.9%		0.0%	

Students had more errors in questions four and five compared to question three and all of the students' errors in question four and 89% of the errors in question five were related to knowing the Theorem or Definition.

Question three. As Table 3 shows all of the students' errors were categorized as Misused data and Logical errors. In this question, the authors noted that the issue was related to determining the unknown variable. Six of the students simply stated the side length as 1 without offering any explanation or solution for how they found the answer. Seven students correctly applied the Pythagorean theorem, however, they assumed the sides were of length 1 and treated the hypotenuse as the unknown, ultimately calculating the hypotenuse to be √2 (see Figure 2 part A). Additionally, two students, who provided the correct side length, considered one side to be 1 and the hypotenuse to be √2, then used the Pythagorean theorem to confirm that the other side was also 1 (see Figure 2 part B).

Part A Part B

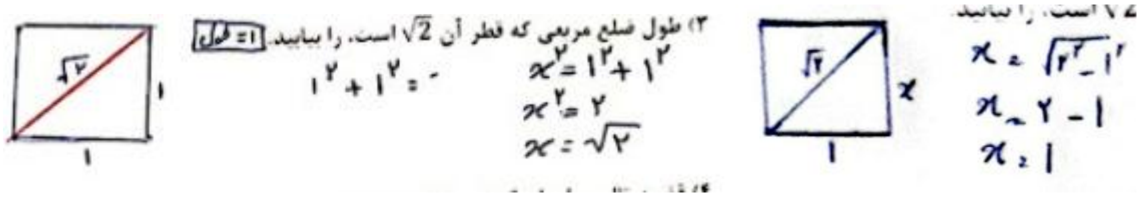


Figure 2. Examples of Students' Errors in Finding the Side of a Square When Hypotenuse was √2.

Question four. Out of 19 incorrect answers for question four, all were related to the Distorted Theorem or Definition category. Sixteen of these students described congruent triangles, with 14 stating that the corresponding angles and sides should be equal, and two mentioning that the triangles can be placed on top of each other. One student stated that two triangles are similar if two corresponding angles are equal, while another student mentioned that if all corresponding angles are equal, the triangles are similar. These two statements were correct but did not refer to the corresponding side proportionality in the definition of similar triangles.

Question five. In this question, the authors observed a similar issue to question four, where 16 cases defined congruent triangles instead of similarity. The other main issue observed in question five was that most students mentioned only one case of the types of right triangle similarity, not a general definition. Only, one of the students mentioned that the similarity of two right triangles is a special case of the similarity of all triangles (see Figure 3). This student's answer to question five was a conclusion drawn from her answer to question four, resulting in a general definition that is correct for both questions.

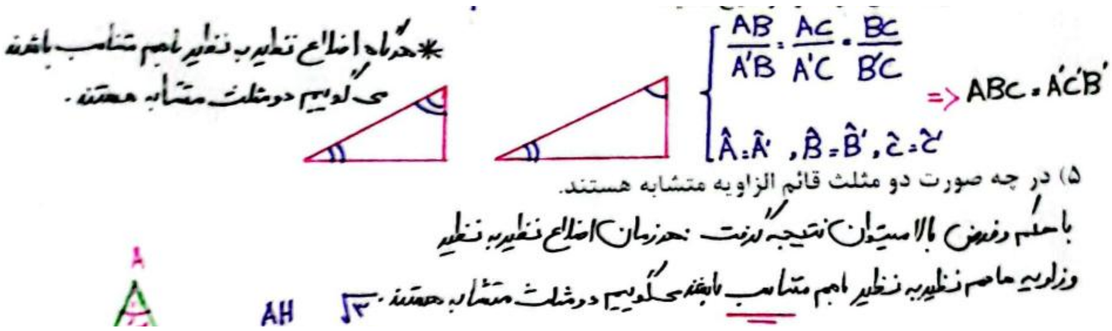


Figure 3. Student's Recognition of the Similarity of Two Right Triangles as a Special Case of the Similarity of All Triangles

Note: متناسب *translates to proportional*

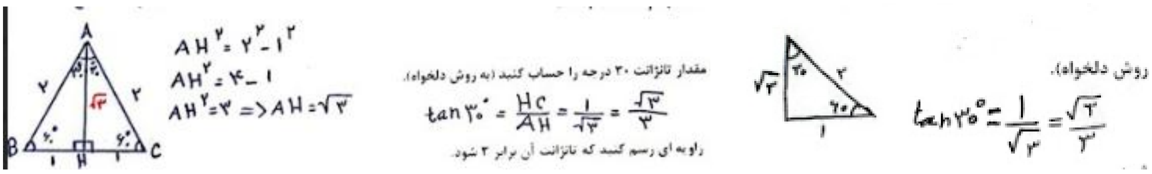
Table 4. Type of Students' Errors in Questions 6,7, and 8, Based on the Movshovitz-Hadar et al., (1987).

		Type of Errors						
		Misused Data	Misinterpreted Language	Logically Invalid Inference	Distorted Theorem or Definition	Unverified Solution	Technical Errors	Total Incorrect
Q 6	Number of Students			3			6	9
	Percentage			33%			67%	
Q 7	Number of Students	2		9				11
	Percentage	18%		82%				
	Number of Students			2			8	10
Q 8	Percentage			20%			80%	

As Table 4 shows, in question seven, most of the students' errors were related to the logical analysis of the question (82% of the errors). In contrast, in questions six and eight students had fewer logical issues in the incorrect answers (33% and 20%, respectively). In questions six and eight, technical errors were the most dominant category (67% in question six and 80% in question eight), while there were no technical errors in students' responses to question seven.

Question six. In this question, 11 students' strategy (out of 33), with correct or incorrect answers, was using an equilateral triangle with a side length of 2, drawing its height, and using the rule opposite side/adjacent side to find the tangent (see Figure 4 Part A). Also, 13 students used half of the same shape with the same strategy to find the tangent (see Figure 4 Part B). Even though 73% of the answers were correct for this question, only two of these students represented their calculation for the length of the height by using the Pythagorean theorem, and most of the errors were related to Technical Errors (67% of the incorrect answers). Also, two of these participants used the same shape but used the rule sin/cos to find the tangent. Furthermore, two students who had the final correct answer ($\frac{\sqrt{3}}{3}$), mentioned that they knew the answer by memorization and did not use the shape to find the answer. Also, two other students who have used the triangle seem to have memorized the shape incorrectly because they have the lengths of the opposite and adjacent sides wrong (see Part C Figure 4).

Part A Part B



Part C

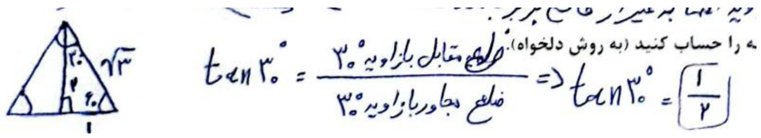


Figure 4. Drawing an Equilateral Triangle to Find the Tangent 30° Angle, Correct Answers.

Questions seven. This question was the one where students made the most Logically Invalid Inference errors compared to other questions (82% of the errors for this question). Seven students drew an angle and created a right triangle when dividing the length of the opposite side by the adjacent side should give 3 (see students' strategies in Figure 5). However, none of these students could correctly find the measure of the angle, nor were the sizes of the sides measured correctly.

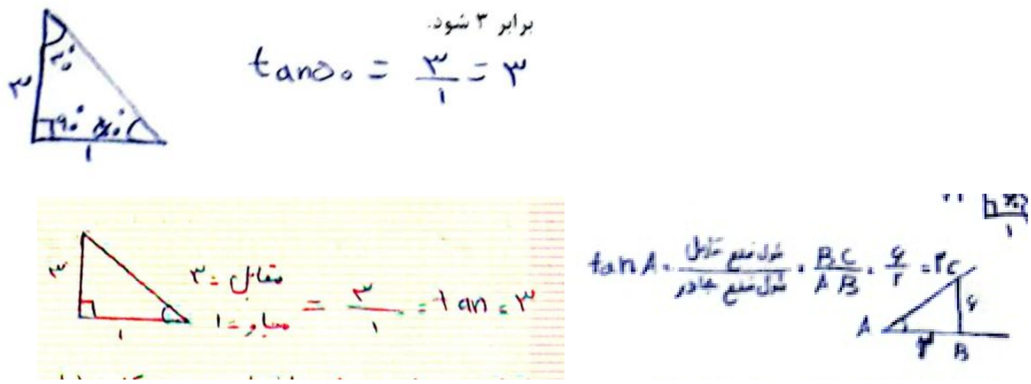


Figure 5. Students' Correct Strategies in Creating an Angle When Tangent is 3.

Another issue observed by the authors was when students multiplied 60° by two and found 120 as the answer or multiplied two to tangent 60°. Since the students knew that the tangent of 60° is √3, they assumed that by multiplying it by two, the tangent of 120° would be 3 (see Figure 6 Part B). Two students used the expression in part A of Figure 5 to remove the square root for the tangent of 60° by multiplying it by two, and four students drew 120° as the answer without providing an explanation or calculations.

Part A Part B

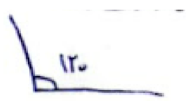
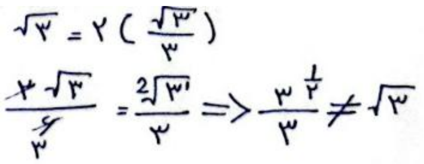


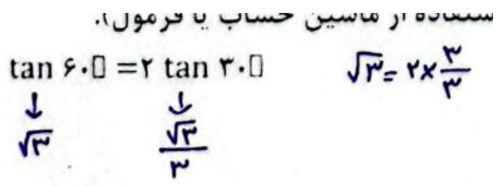
Figure 6. Students Errors in Finding and Angle Where its Tangent is Equal to 3.

Question eight. In this question seven students provided correct answers for the tang60° and tang 30°, however, they did not check the equity of both sides or considered both sides to be equal. The most common error in this question was technical errors (as Table 4 shows), these errors were related to simplifying the multiplication in the right side of the equation ($2 \times \frac{\sqrt{3}}{3}$ or $2 \times \frac{1}{\sqrt{3}}$) that included a fraction and a root sign. These technical errors included a) multiplying two to both the numerator and denominator of the fraction (Part A Figure 6) , b) ignoring the root sign (Part B Figure 7), c) moving two to the exponent to simplify it with the root sign (Part C Figure 7), d) ignoring the two in the right side of the equation (Part D Figure 7).

Part A



Part B



Part C

Part D

Figure 7. Students' Technical Errors in Simplifying Multiplication that Includes a Root Sign and a Fraction.

3.2. Post-test Results

Table 5 shows the number of correct, incorrect, and unanswered questions for the post-test for both groups. As this table shows, the total number of correct answers was higher in Group 1 compared to Group 2 (26% compared to 14%), and the number of incorrect answers was similar in both groups (50% compared to 51%). Students in both groups had similar results in questions one (finding tangent of 20° by drawing a triangle) and five (a real real-world question about tangent); most of the students did not answer these questions, or their answers were incorrect; none of the students' answers for these two questions were correct.

The differences in students' performance were obvious in questions two (finding the tangent of 37.2° by shape, calculator, or Python) and four (finding the length of a side of a triangle by giving the angle size). In Group 1, 71% of the students' answers were correct for question two (compared to 13% in Group 2), and 50% of the students' answers in Group 1 were correct for question four (compared to 0% in Group 2). In contrast, students in Group 2 had a higher number of correct answers for question three (a real-world question about finding the length of a right triangle using sine); 56% of the students' answers in this group were correct (compared to 7% in Group 1).

Table 5. Comparing the Number of Correct or Incorrect Answers for Both Groups in the Post-test

	Question Number	**1**	**2**	**3**	**4**	**5**	**Total**
Group 1 (14 students)	Correct	0	10	1	7	0	18
	Percent	0%	71%	7%	50%	0%	26%
	Incorrect or Incomplete	13	3	8	5	7	36
	Percent	93%	23%	57%	36%	50%	51%
	No Answer	1	1	5	2	7	16
	Percent	7%	7%	36%	14%	50%	23%
Group 2 (16 students)	Correct	0	2	9	0	0	11
	Percent	0%	13%	56%	0%	0%	14%
	Incorrect or Incomplete	13	3	4	15	5	40
	Percent	81%	19%	25%	94%	31%	50%
	No Answer	3	11	3	1	11	29
	Percent	19%	69%	19%	6%	69%	36%

Type of Students' Errors in Post-test

Table 6 and Table 7 show Group 1 and Group 2 students' type of errors in the posttest based on the Movshovitz-Hadar et al., (1987) framework. As the tables show there were not huge differences in the type of errors in the questions between the two groups.

Technical errors in the experimental group were much fewer compared to the control group (15 out of 28 errors in Group 2 compared to 4 out of 15 errors in Group 1).

A big difference in the type of errors was observed in question four; students in the experimental group had only two technical errors, while in the control group, 13 errors (87% of the total errors for this question) were related to technical errors. Since the type of errors was not different in both groups for other questions, the following sections will refer to common mistakes in both groups unless there was a difference in the common errors observed by the authors.

Question one. None of the students in these groups used drawing and measurement to find the tangent of 20°; all students who had correct final answers used a calculator or Python to find the answer and some of them drew an angle without creating a right angle and measuring the sides. One of the observations made by the authors was about the accuracy of the students' drawings of 20° angle; in many cases (except for two students), students' drawings were not accurate. As shown in Figure 8, the student's drawing was greater than 20°.

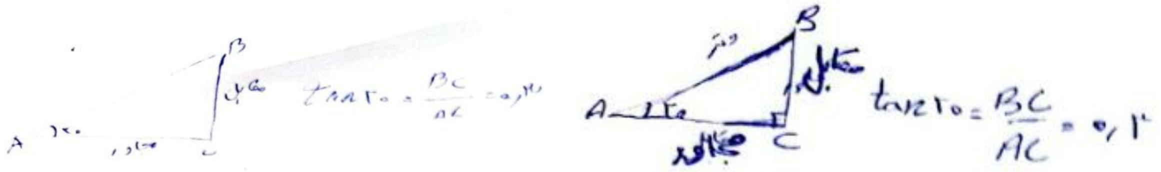


Figure 8. Students’ Problems in Drawing 20° Angle in Post-test.

Question two. When students were asked to find the tangent of 37.2 using the given shape and a calculator in the control group only two students compared the findings from different tools. One of them stated that the answer obtained by using the calculator was more accurate than by using the shape and the other student mentioned that the answer by shape is more accurate. In the experimental group, among the eight students who compared the results, two mentioned that the answer provided by Python was more accurate, while six mentioned that the answer provided by Python was different. None of the students in either class explained why they thought the answers were different or more accurate (See Figure 9).

Table 6. Type of Students’ Errors in Post-test Based on the Movshovitz-Hadar et al., (1987), Group 1.

		Type of Errors						
		Misused Data	Misinterpreted Language	Logically Invalid Inference	Distorted Theorem or Definition	Unverified Solution	Technical Errors	Total Incorrect
Q1	Number of Students							
	Percentage							
Q2	Number of Students						2	2
	Percentage						100%	
Q3	Number of Students			7				7
	Percentage			100%				
Q4	Number of Students						2	2
	Percentage						100%	
Q5	Number of Students	1		3				4
	Percentage	25%		75%				

Table 7. Type of Students' Errors in Post-test Based on the Movshovitz-Hadar et al., (1987), Group 2.

		Type of Errors						
		Misused Data	Misinterpreted Language	Logically Invalid Inference	Distorted Theorem or Definition	Unverified Solution	Technical Errors	Total Incorrect
Q1	Number of Students						2	2
	Percentage						100%	
Q2	Number of Students			2				2
	Percentage			100%				
Q3	Number of Students			4				4
	Percentage			100%				
Q4	Number of Students			2			13	15
	Percentage			13%			87%	
Q5	Number of Students	1		4				5
	Percentage	20.0%		80%				

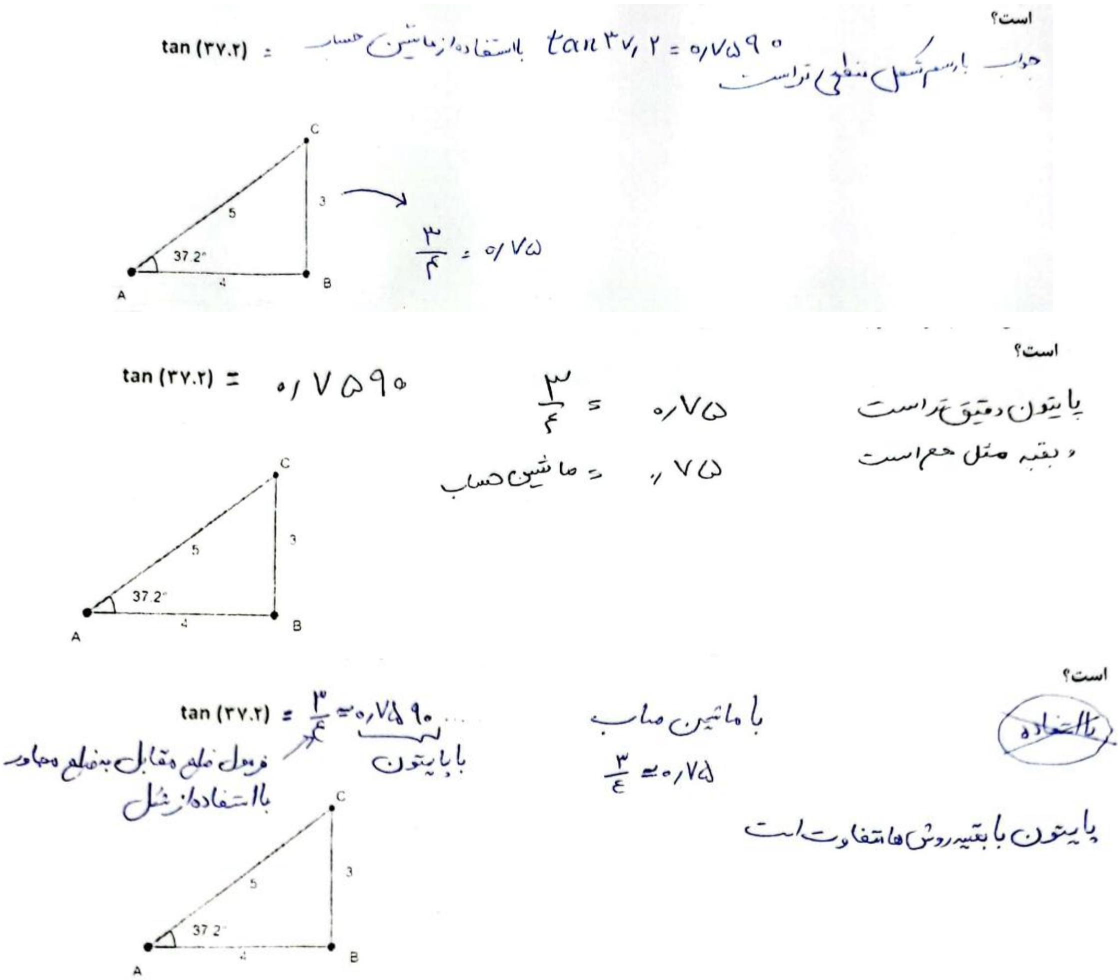
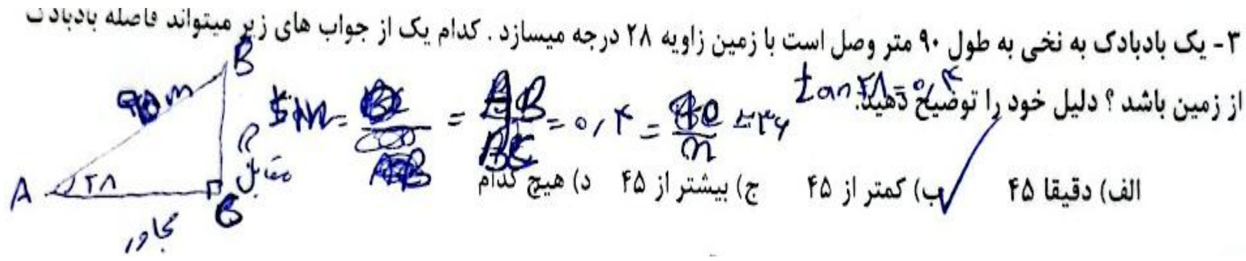


Figure 9. Comparing the Answers from the Shape with the Answer from Calculator and Python.

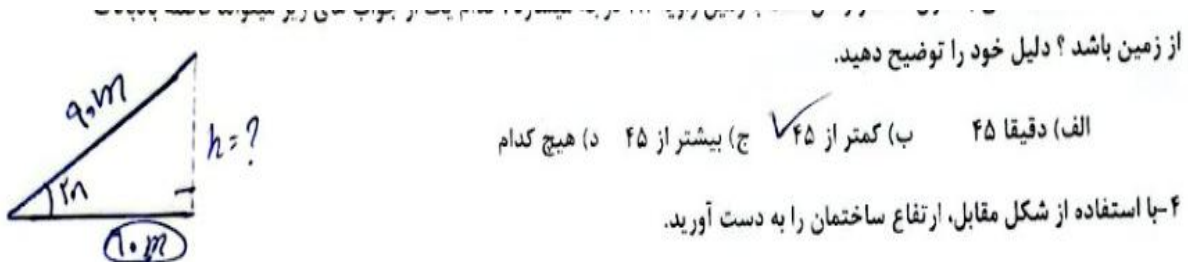
Question three. In this question, students in the control group had more correct answers compared to the experimental group (56% compared to 7%, as Table 5 shows). Nine students in the control group used the sine rule and realized that the given side was the hypotenuse. Four errors observed in the responses from this group (see Table 7) were related to logical errors: two students chose the option less than 45°, mentioning that the angle of 28° is acute, while the other two errors were related to solving the equation. The common error observed in the experimental group involved confusion regarding which sides of the triangle were given and which trigonometric rule should be applied to find the unknown side. Where the length of the hypotenuse and the angle were given, eight students (out of 14) used the tangent formula and assumed the given length was the adjacent side (See Figure 10).

A few of the students' work (see Figure 10) in the experimental group indicates this confusion; however, all of these students used tangent to find the answer. In Part A, Figure 10, the student initially realized that she needed to use sin but then changed it to tangent. Despite marking the opposite side as unknown, she divided the hypotenuse by the opposite side to find the unknown. Part B also shows the student's confusion about what side length is 90 meters. In Part D, the student used the correct measure for the hypotenuse. However, when attempting to use the tangent rule, the student mistakenly used the 62° angle, which is the complementary angle of 28°.

Part A



Part B



Part C

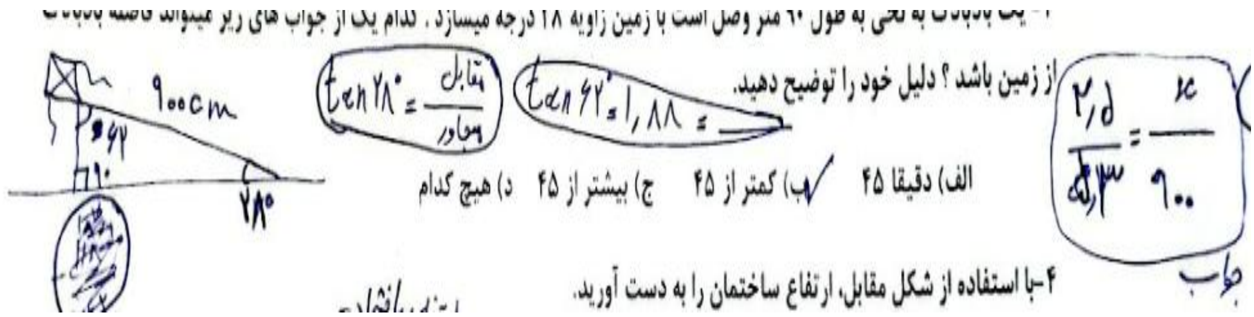
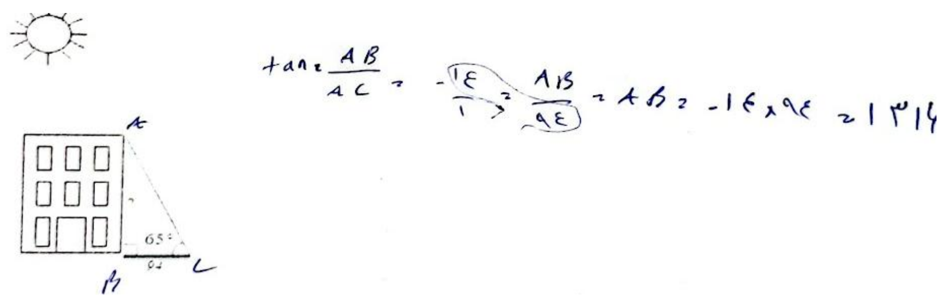


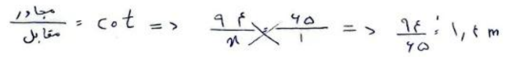
Figure 10. Using the Tangent Formula Instead of Sin to find the Height of the Triangle

Question four. As Table 6 and Table 7 show, students in the control group had more technical errors compared to the experimental group (13 compared to two). The errors that were observed in this group included: missing the decimal point (Figure 11 Part A), using the size of the angle instead of using the tangent of the angle (Figure 11 Part B), putting a negative sign for the tangent 65° (Figure 11 Part C), mistake in solving fraction equation (Figure 11 Part D), and error in the formula for the tangent (Figure 11 Part E), error in changing the tangent of 65° as a decimal point to a fraction (Figure 11 Part F).

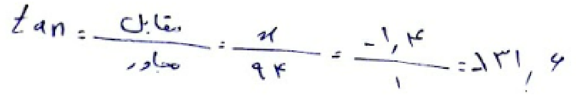
Part A



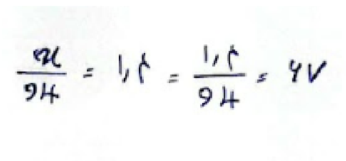
Part B



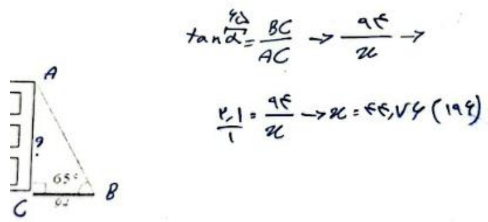
Part C



Part D



Part E



Part F

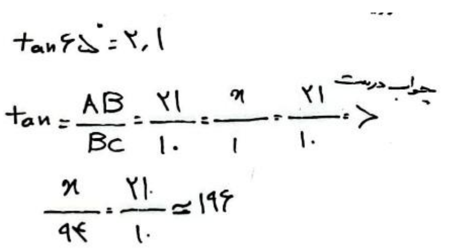
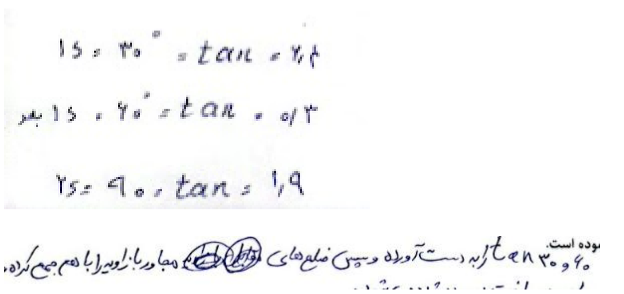


Figure 11. Students Errors in Finding the Height of the Building by Using Tangent or Cotangent

Question five. As shown in Table 6 and Table 7 most of the students' errors in both groups were logical errors; 80% of the errors in the control group and 75% of the errors in the experimental group. The common mistaken idea in solving this question was either finding the tangent of 30° and 60° and adding the two answers, or finding the opposite side by using the tangent of both ingles and adding the length of opposite sides (see Figure 12).



1s=30^0 tan= 6.4
1s= 60^0 tan=0.3
2s= 90 tan= 1.9

First, find the tangents 30 and 60
Then add the length of the opposite sides.

Figure 12. Students Errors in Finding the Height by Using Tangent

4. Conclusion

The study's results indicated that, in the pretest, students had fewer correct answers for definition problems compared to questions involving drawing angles, using trigonometric rules to solve problems, or finding the value of a tangent of an angle.

This study showed that the number of correct answers in the experimental group was slightly higher than in the control group in the post-test. However, the types of errors were not significantly different between the two groups (except for one question).

Technical errors in the experimental group were fewer compared to the control group.

In one of the post-test questions (question three) that required students to use the sine rule (since the hypotenuse was given in the question), the control group had more correct answers compared to the experimental group. Many students in the experimental group used the tangent to find the answer, possibly because they relied on Python to calculate the tangent during the intervention program, without carefully reading the question and realizing that the given side was the hypotenuse.

Eight students who compared the results from Python, the calculator, and the shape noticed that the answer provided by Python was more accurate or different. However, none of the students provided an explanation or reasoning for this difference.

5. Discussion

The findings of this study, specifically from the application of trigonometry concepts in questions three, four, and five of the post-test, show similar types of errors found in the findings of Dewanto et al. (2017) and Fahrudin and Pramudya (2019). Similar to Dewanto et al. (2017) study we found that that students had difficulty interpreting stories into pictures and made miscalculations during problem-solving. However, our findings contrast with theirs in that they found only a few students were confused once a drawing was made for a question. Fahrudin and Pramudya (2019) found that one of the students' problems in solving trigonometric equations using sine and cosine concepts was incorrectly determining the formula, theorem, or definition needed to answer the problem. Similar results were found in our study; in question three of the post-test, where the length of the hypotenuse and the angle were given, eight out of 14 students used the tangent formula instead of the sine formula to find the answer.

A study by Rohimah and Prabawanto (2019) showed that 34.81% of students had calculation errors, and 30.38% made errors in drawing conclusions while solving equations involving sine and cosine. Our study found similar results regarding students' errors in verifying the correctness of equations using tangents. Although some students provided correct answers for tangent 60° and tangent 30° in equation tan 60=2tang 30, they did not check the final answer or if they tried to simplify the answer, the most common errors (80% of errors, as shown in Table 4), were technical errors related to multiplication in the $2 \times \frac{\sqrt{3}}{3}\ or\ 2 \times \frac{1}{\sqrt{3}}$.

6. Implications and Recommendations

Teachers need to focus on possible misconceptions students may have in learning a concept (Chua et al., 2016). Utilizing learners' mistakes can help them create effective teaching strategies (Fennema et al., 1996) that minimize errors in solving trigonometric questions. The findings of our study could assist teachers in understanding the types of errors students make, particularly in questions related to the tangent concept and its applications.

The study covered only tangent questions, other studies could also be conducted so that more trigonometric subjects could be used to give a wider view of the errors encountered in solving problems related to sin, cosine, or cotangent in trigonometry.

The intervention in this study was limited to only a few sections on an introduction to the programming language, Python, in finding tangents of angles and did not focus on different programming skills. Other studies should be conducted on the use of more education based on Python programming in teaching trigonometry concepts and exploring its effect on students' errors.

Ethics Statement: This study involved student participants. Prior to participation, informed consent was obtained from the students' parents or legal guardians through signed consent forms. Participation was voluntary, and all participants were informed about the purpose of the study and their right to withdraw at any time. The confidentiality and privacy of participant information were maintained throughout the research process.

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